STAFF REPORT

WATER FOR ENERGY DEVELOPMENT IN THE
NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN REGIONS

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Prepared for Natural Resource Economics Division
Economics, Statistics, and Cooperatives Service
U.S. Department of Agriculture
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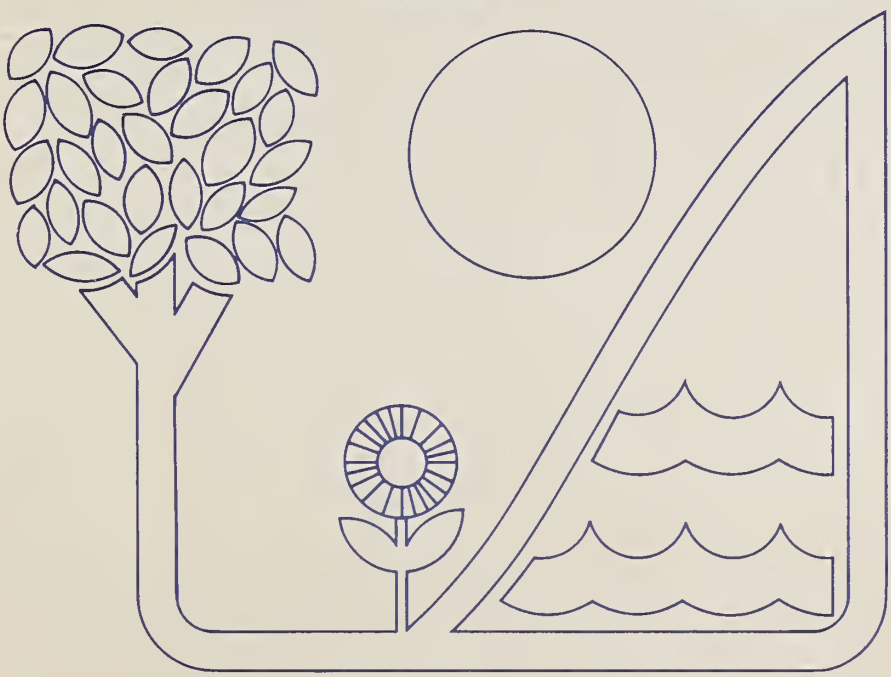

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WATER FOR ENERGY DEVELOPMENT IN THE NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN REGIONS. By S. Lee Gray, Professor of Economics, Colorado State University, Edward W. Sparling, Assistant Professor of Economics, Colorado State University, and Norman K. Whittlesey, Professor of Economics, Washington State University; prepared for Natural Resource Economics Division, Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture, Washington, D.C. 20250. December 1979.

ABSTRACT

Converting coal or oil shale to useable energy requires large quantities of water. There is not enough water in the Upper Colorado Basin near oil shale deposits to permit a large shale oil industry, unless water rights were purchased from farmers and ranchers. Local agriculture could then suffer drastically. By contrast, there is enough water for widespread conversion of coal in the Northern Great Plains to both electricity and synthetic fuel. However, most of the water is not near most of the coal. Either the water will have to be piped to the coal, at great expense, or the coal must be shipped to the water, whether within or outside the Northern Great Plains States.

Key words: Water resources; energy development; coal; oil shale; Northern Great Plains; Rocky Mountains

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SUMMARY *

The total unused flow and existing storage of the Yellowstone-Missouri River system upstream from Garrison Dam are enough to supply cooling and process water for many potential coal-fired electric plants and coal gasification or liquefaction facilities in the Northern Great Plains (NGP). However, the irregularity of flow reduces the dependable supply to the low-flow amount at points of withdrawal. Furthermore, much of the coal is not near most of the water, necessitating transport of one or the other. Interstate compacts and Indian water rights are also constraints. Therefore, at this time the availability of water to help develop the energy potential of the NGP's vast coal deposits is constrained not by the total amount of water, but principally by its distribution over time and space as well as by institutional obligations which seem extremely difficult to relax.

An important issue is whether numerous coal-using facilities should be established at mine-mouth locations, particularly in Northeastern Wyoming, where coal mining is expanding more rapidly than anywhere else in the Nation. The Platte, Powder, and Tongue River Basins in Northeastern Wyoming are the most water-short areas of the NGP. In these basins, unlike the Mainstem Missouri, unused surface flows are extremely small relative to coal-processing needs.

If mine-mouth facilities are to be built, or even if large slurry pipelines for coal transport out of the region are to materialize, water availability in these basins will need to be sharply increased. Otherwise, massive coal shipments by unit trains would be the only way to handle the large increases in coal output now contemplated. A much

* Prepared by Joseph R. Barse.

greater volume and frequency of these unit train shipments could, in turn, place severe strains on railroad link capacities and cause more and more inconvenience for towns and cities along the way. Thus, the potential for increasing water availability in Northeastern Wyoming is a significant matter.

If enough new water storage capacity were constructed in the Yellowstone Basin, an additional 2 million acre-feet could be available annually (even after instream, aquatic needs are fully met). However, the dam and reservoir construction would be costly and extensive. Widespread environmental damage would result. The dams and reservoirs would make additional water available downstream, principally in Eastern Montana. Construction of more coal processing plants there would become technically feasible. However, for any of this storage to add much to the water supply in Northeastern Wyoming, aqueducts for interbasin water transfer would have to be built. Some have been proposed.

If these were constructed, additional water for coal-using facilities near the major coalfields in Northeastern Wyoming could be made available in the Platte, Powder, and Tongue River Basins from the Green, Bighorn and Yellowstone. But, these aqueducts would be large, long, and have high pumping heads, obviously a very expensive solution to the problem of water scarcity in coal mining areas.

Should added investment in dams, reservoirs, and aqueducts be deemed too costly as a means of obtaining more water for coal development in the basins with greatest water scarcity, exploiting the previously-untapped deep aquifers may be the only way left. Groundwater in shallow aquifers is really not available because it is already in heavy demand and is often connected closely to surface flows.

But, data on the extensive, deep Madison aquifer are scarce. Water quality is low and variable, and may deteriorate further if used intensively. Moreover, wells drilled into the Madison do not yield uniform quantities because of the low porosity of the rock and variable fracturing. Therefore, results from tapping the formation are not predictable, and may not be stable over time.

Consequently, the conclusion is that water availability poses severe problems for a potential large scale coal-processing industry in Northeast Wyoming, lesser problems in Eastern Montana and few problems in Central North Dakota, although the lignite fields of Southwestern North Dakota are much farther from the larger water supplies.

In those parts of Colorado, Utah, and Wyoming where oil shale is the major undeveloped energy resource, many of the constraints on water availability found in the NGP coal regions are also present, but more severe, and seem likely to have a more inhibiting effect on energy development than in the NGP. Unused flows are much smaller relative to total flows than in the NGP. And, the "mis-match" between the location of the richest and largest oil shale deposits (in Northwestern Colorado) and the greatest amount of unused water (in Northeastern Utah and Southwestern Wyoming) is much sharper than any coal-water "mis-match" in the NGP.

Moreover, because of the bulkiness of the raw oil shale rock, it cannot be transported beyond the mine-mouth, in contrast to coal. Therefore, except for the unlikely construction of costly aqueducts to bring process water to oil shale retorts, the development of a retorting

industry in any locality likely will be limited by the availability of unallocated and unused surface water in the immediate sub-basin, with several major exceptions.

If sub-basin markets for water rights are allowed to function freely--and this is certainly a public policy issue--much irrigation water will be bid away from agriculture by the oil shale companies. With water worth an estimated $20 per acre foot for irrigation, but worth $200 in the oil shale industry, holders of water rights would find it profitable to sell considerable quantities to industry. The impact on irrigated farming in the oil shale regions of Colorado could be severe. As much as 81,000 acres out of 413,000 acres currently irrigated could go out of production. However, it would take a large-scale oil-shale industry of 2 million barrels per day in Colorado to have such a large impact on agriculture. Additional capacity might also be constructed in Utah and Wyoming, although the shale deposits of those States are not nearly as rich as those of Colorado's Piceance Basin, and therefore less economic to exploit.

Nevertheless, if the free-market transfer of water rights from agriculture to the oil shale industry were severely restricted, the effect would be to greatly restrain Colorado development, possibly advancing it in Utah and Wyoming where more unused water is still available.

All the above must be qualified, though, by considering the relatively undeveloped state of the art in the oil shale industry. The need for water may be reduced by technological advance. De-watering of oil shale mine zones might then be able to supply a substantial portion of water needs.

CHAPTER I

INTRODUCTION AND PLAN OF THE REPORT

Introduction

The purpose of this report is to describe water resource use, availability, and potential for satisfying large-scale coal and oil shale developments in the Northern Great Plains and Rocky Mountain Regions of the United States. The description represents the first phase of a project whose ultimate objective is the construction of an interregional model of coal and shale oil production and processing in the United States.

Before describing the water resource base in these regions, it is useful to recall a few of the unique characteristics of water which cause complex economic and institutional problems in development and allocation among alternative and often competing uses. These comments are general in nature and are of importance both to the description and subsequent analytical phases of the project.

The stage for discussion is set by the increasing attention focused on the large coal and oil bearing shale deposits in the two regions as a means to help meet the projected energy requirements in the U.S. The mere existence of these reserves does not necessarily guarantee that they can, or should be developed. Development depends on a number of factors one of which, given current technologies in extraction and processing, is a substantial amount of water.

Since water supplies are no longer sufficient to meet all the needs of an expanding number of uses, the problems and conflicts associated with development and allocation may be quite severe. Water use and development must be placed into a total perspective which contains the interrelations

between current uses and regions and which encompasses future, as well as existing, impacts.

The Nature of Water[1/]

Water, as a natural resource, is for the most part classified as a flow, or renewable, resource. Under certain circumstances, however, it can take on the essential character of a stock, or nonrenewable, resource. Water seldom stays in one location for sustained periods of time and thus it is further classified as a fugitive resource. This fugitive nature or characteristic is evidenced in all phases of the hydrologic cycle. Obviously water in a gaseous state may be transported vast distances in the atmosphere before entering the land phase of the cycle in liquid or solid form. In the land phase of the cycle, water may almost immediately reenter the atmosphere through evaporation; it may percolate through the soil to underground aquifers; it may be stored in solid form prior to entering run-off; it may enter surface bodies of water such as lakes, rivers, and streams.[2/] The mobile, flowing nature of water is particularly important, for our purposes, in the land phase of the cycle since it is here that the resource becomes available for man's use and, because of the fugitive characteristic, reuse. Water use, for the present, is divided broadly into withdrawal, or offstream uses such as irrigation, municipal and industrial uses, etc., and nonwithdrawal, or instream, uses such as water power, recreation, waste assimilation, and navigation. Further identification of use is in terms of nonconsumptive and consumptive use. The latter concept is basically the difference between quantities of water withdrawn and the amount which is available for subsequent reuse. We will return to the concept of use subsequently.

Regional and Seasonal Variation in Supply and Demand

On the supply side, the nation as a whole appears to have an abundance of water to meet current and foreseeable future needs. Average annual precipitation in the coterminous United States is approximately 30 inches per year, with average annual run-off of some 1,200 billion gallons per day. There are, additionally, large underground water supplies. Conclusions based on these averages must, however, be interpreted with care. The distribution and timing of water supplies varies widely between and among geographic regions. A dramatic example of geographic variation in supply is afforded by comparing parts of the Columbia-North Pacific region, which receive in excess of 200 inches per year.[3/] These regional variations are often compounded by yearly and seasonal variability, a lack of uniformity which constitutes a major physical source of water problems in the nation.

Water consumption rates also display considerable variation between geographic regions and, within a given region, from season to season. Unfortunately, higher rates of use, in either the location or time dimensions, often do not correspond with peaks of water availability. Thus, water storage facilities and conveyance systems are built to balance seasonal and geographic discrepancies in demand and supply.

Dimensions of Water Use

These considerations have promoted analysts in the water resources field to refer to several dimensions in describing water use. Three of these, quantity, time and location, have historically formed the basis of property right specifications regarding the allocation of annual supplies, particularly in the western United States. A fourth characteristic or dimension is water quality, which has played a role in establishing water rights in the eastern

part of the country since the 1880's. Rising concern for water quality in interstate and international river basin compacts and the emergence of state-by-state water quality standards indicates that water quality considerations will play an increasing role in reallocation decisions concerning western water rights. These dimensions, either as general characteristics or as specific use components, comprise an integral part of the water problem and thus alterations in any of them may be expected to have a significant impact on water values and on development and allocation decisions. Alterations in any of the dimensions may be achieved, but costs of storage, conveyance and treatment facilities, and institutional incentives will determine whether, and to what extent, these alterations will be undertaken.

The Water Problem

Consideration of these dimensions and the reuse potential implies that actual physical stringency of water supply is not the only, nor perhaps the most important, part of the water problem. While it is true that most regions in the United States, even the most humid, do at times face physical scarcity of supplies, the reuse potential renders measured water flows imprecise as indicators of the potential for productive use of the resource. Even if there were some absolute limit on total supplies, the amount available to any given use is not fixed. In principle, more is available at a higher price if sufficient time is allowed for developing storage, conveyance and treatment facilities. This argument suggests an institutional scheme which encourages certainty and flexibility of tenure in water rights, conditions which have not always been met by prevailing systems. Nonetheless, the argument is valid and indicates that the nature of problems involving water is one of conflict among alternatives stemming from economic scarcity rather than physical shortage

The conflicts may be of various types; i.e., among uses (irrigation, coal development, domestic, etc.), between location or region of use, between present and future uses or between resources used for water development and those same resources in alternative purposes.

The Concept of Water Use

The physical characteristics of water, in particular its mobile, flowing and multi-dimensional nature pose some interesting problems in identifying what constitutes use. It is quite common to distinguish, as we have done previously, between withdrawal and nonwithdrawal uses and between consumptive and nonconsumptive uses. Generally, withdrawal uses are the major consumptive uses, but even here it is unlikely that the entire amount withdrawn will be "consumed" (lost by evaporation). A portion will likely be available for reuse. On the other hand, instream uses are normally classified as non-consumptive uses. However, storage of water for instream use can result in a substantial loss due to evaporation or seepage. The unconsumed portion may be greatly altered in quality, time, and location characteristics.

The reuse potential for water makes it unique from other resources in that use at one time and location for a specific purpose does not necessarily preclude its use at a later time, at a different location, for the same or other purpose. Water "used for power generation (released from storage) is available for downstream use in a number of purposes. Contrast this with, for example, labor used in producing a consumer good. The implication of this discussion is that water use cannot, in most cases, be viewed independently of potential alternative utilizations. In a typical river basin several alter-native uses for the resource may exist and one use may affect others through any or all of the quantity, quality, time, or location dimensions. The possible interrelations among these various alternatives may be conveniently cast in the

language of competitive, complementary and supplementary relations of production economics.[4/] The competitive relationship, for our purposes, is represented by situations in which increased water use for one purpose leads to a reduction in water use by another. Economic literature abounds with discussion of competitive demands for water used in agriculture and for water used in industrial and municipal uses. The complementary relationship is such that an increase in (water) use by one alternative is accompanied by an increase in the availability of water for another. A ready example of this relationship is given by navigation and recreational boating. As increased water is available for navigation, recreational use of water may also increase, at least to some limit.[5/] Supplementarity in water use refers to cases in which an increase in water use, say water stored for power generation, imposes no change in the amount available for, say, sport fishing in a stream. If intake to a storage reservoir is sufficient to allow both increased storage for peak power requirements and releases sufficient to maintain the fishery the supplementary relationship holds. Examples may be employed to express these relationships in terms of any of the four dimensions.

Accounting for these types of interrelationships indicates a general definition of use--use is any alteration in quality, timing, location or quantity. While the subsequent analytical phases of the research effort may not consider water use in the systems context suggested by the preceding discussion, these considerations should be kept in mind and used as qualifications to the results of the analysis of water used for coal and oil shale development. Consideration of interdependencies in use may well lead to the specification of water use constraints to protect the vested interests of other water users in the study area.

The Value Issue

To this point our discussion has been predominantly in terms of physical characteristics and relationships. However important they may be, rational decisions pertinent to water resource development and allocation require that some estimates of the value of water in alternative uses be made. In many cases, resource allocation and development is amenable to the operation of a market system in which prices serve these functions. However, the fugacious nature of water resources, and the uncertainty of supply make it difficult to establish the property rights upon which the market price system depends. Thus, there is a lack of well-defined market institutions to generate prices to allocate water resources. The market for water cannot normally be tested in terms of quantities of water demanded at alternative prices and thus analysts must resort to estimated, or synthetic market prices ("shadow prices" in economic jargon). These shadow prices represent the willingness to pay for water in alternative uses and provide a basis for selecting one alternative use over others.

There are several conceptual issues which must be accommodated in subsequent analysis, in regards to the question of value. While we make no attempt to discuss these completely in this initial report a brief listing is desirable. First, we have defined use in terms of any alteration in quantity, quality, timing, or location for economic benefit. Value estimates should, in principle, be net of effects (positive or negative) which an increment of use engenders elsewhere.

Second, value estimates must be comparable in terms of these four dimensions. Water is a bulky commodity and thus transportation costs may be large relative to value at point of use. The net value of water will thus decrease rapidly with increasing distance from the point of use. Water also must

frequently undergo some form of processing. Hence, there will be differences in the value of raw water as compared to water treated to a quality suited for a specific use. Such considerations must be accommodated in order to assure comparability of values in different uses.

A third issue concerns the question of "value to whom"; i.e., the accounting stance adopted. Three principal stances may be identified: (1) the national perspective; (2) the regional or state perspective; and (3) the private individual user or firm.

Finally, an issue to be resolved involves the distinction between short and long-run values. Value of water, as a producer's good, is likely to be greater in the short run than in the long run. Many studies of the value of irrigation water involve short-run value estimates. However, from the national perspective, evaluation of water development dictates a long-run concept. This may be derived from short-run estimates by adjusting for costs of overhead items.

Outline of the Report

The remainder of this initial report consists of the description of the water resources of the Northern Great Plains and Rocky Mountain Regions. Chapter II provides a discussion of the major legal and environmental constraints to the development and allocation of water for producing and processing coal and oil shale. Included in the discussion are: (1) the riparian and appropriations doctrines of water rights allocation as pertinent to the states of the two regions; (2) interstate compacts affecting the allocation of interstate waters among the states involved; (3) a brief discussion of federal constraints to water resource development; and (4) environmental constraints with regard to water and air.

Chapter III contains the profile of water use and availability in the Northern Great Plains and includes a compilation of existing data on: (1) estimated current use of surface water; (2) estimates of present and future availability of surface water; (3) estimates of projected future use of surface water; (4) characteristics of regional water quality, and (5) a discussion of ground water availability in the region.

Chapter IV contains the profile of water use and availability in the Rocky Mountain region and discusses current use of water, projected future use, regional water quality and ground water availability.

CHAPTER I FOOTNOTES

[1]The following discussion draws heavily on Robert A. Young and S. Lee Gray, Economic Value of Water: Concepts and Empirical Estimates. National Technical Information Service PB-210-356, U.S. Department of Commerce, Springfield, Virginia, Chapters 1 and 3, March, 1972.

[2]Jack Herschleifer, James C. DeHaven, Jerome W. Milliman, Water Supply: Economics, Technology, and Policy. University of Chicago Press, Chicago and London, 1969.

[3]The Nation's Water Resources, U.S. Water Resources Council, Washington, D.C., 1968, p. 3-2-1.

[4]With some modification, the argument could be made in terms of externality theory. For a presentation in this light see Young and Gray, Economic Value of Water: Concepts and Empirical Estimates, pp. 55-57.

[5]Recreational boating may increase up to the point at which congestion becomes an issue. At that point, the competitive relationship obtains.

CHAPTER II

CONSTRAINTS TO WATER RESOURCE DEVELOPMENT AND ALLOCATION

Introduction

Any consideration of water resource development and allocation must include recognition of the limits imposed by various legal, institutional, economic, social, environmental constraints. These constraints dictate to a great extent the magnitude of water development, the types of use to which the resource may be put, the location of water related developments and the transfer of water between regions and uses. A complete discussion of constraints to water development in the two regions would itself constitute a major effort and is precluded by the time, financial, and professional inputs available to this study. The discussion which follows is therefore directed only towards a summary of the major constraints to water development and allocation in the two regions. The major emphasis is placed on legal constraints as opposed to social, cultural, aesthetic and ecological considerations.

Legal Constraints

General Considerations. Legal constraints include individual state water laws, interstate compacts, the United States Constitution, laws and treaties of the United States and federal statutory provisions. The primary reasons for legislation in the water resource area parallel those for institutional development in general. Increasing demands for water have led to scarcity, manifested in one of several ways: actual stringency of supply, degradation of quality of supply, inappropriate timing of supply, and geographic discrepancies in supply. Scarcity in whatever form leads to conflicts among users or regions and to uncertainties regarding tenure. The legal system

governing water rights, development and allocation emerges as a means for resolving such conflicts.

Two essential components of water rights are certainty and flexibility of tenure. The former enables the resource user to know the quantity of resource available for use at a particular time and location. The latter permits bilateral or multilateral negotiations for transferring rights to use. The fugitive nature of water, regional differences in the nature of water problems, and physical interdependence among users render it difficult to provide these essentials under a single institutional structure. As a result, two principal doctrines regarding property rights in water have been developed; the riparian doctrine and the appropriations doctrine.

The riparian doctrine, developed under English common law, permits the owner of land contiguous to a natural body of water to use the water so long as use does not unreasonably alter the quantity and quality of water available to downstream riparian users. These rights are independent of actual use (or lack of use) and are the same for all riparians on the body of water. Rights are specified as to quantity only if apportioned by the courts. Tenure is secure against non-riparian uses but flexibility of tenure is found only among traditional beneficial uses on riparian lands, through the sale of such lands. Flexibility of tenure between riparian and non-riparian uses is virtually non-existent.[6/]

The status of the riparian doctrine in the Northern Great Plains states has been summarized by Hutchins.[7/] Two of the states, Montana and Wyoming, have completely repudiated the riparian water use doctrine. The status of the doctrine in North Dakota and South Dakota is somewhat less well defined. Both states, during the 1860's recognized the doctrine. The doctrine, in

North Dakota, was repealed in 1963, and in 1968, "the state supreme court apparently concluded unused riparian rights for nondomestic purposes could be validly abrogated . . . at least as against appropriative rights . . ."[8/] In South Dakota, the state legislature, in 1955, enacted a statute modifying the doctrine by "restricting vested riparian rights for nondomestic purposes to actual beneficial use of water at the time of enactment or shortly thereafter."[9/] The Rocky Mountain States, Arizona, Colorado, New Mexico, and Utah do not recognize the riparian doctrine.

The appropriation doctrine appears to have been adopted to meet the problems peculiar to the arid and semi-arid portions of the Western United States. Under this doctrine, "beneficial use is the basis, the measure, and the limit of the water right."[10/] The allocation principle is one of "first in time, first in right" to the natural flow of water applied to beneficial use. Water rights relate specifically to the time of appropriation, to a quantity of water to be applied at a given location and for a specified purpose.

In contrast to the riparian doctrine, there is no limit to the number of claimants to rights of use. Each right holder is protected by the date of his right and thus tenure security against all other users is established (although the right is perfected and sustained only by sustained beneficial use.) Tenure flexibility is, conceptually, much greater than under the riparian doctrine since resource movement to non-riparian lands is allowed.[11/]

The appropriations doctrine had been accepted by all of the contiguous western states and territories by 1900. Arizona, Colorado, Montana, New Mexico, and Wyoming all had recognized the doctrine by 1875. Nebraska, North Dakota, South Dakota and Utah all recognized the doctrine by 1900.

Current administration of water rights in the two regions is based largely on the procedures developed in Colorado and Wyoming. While there are variations among the states, state supervision and control usually rest with the state engineer (or other official) and the courts.[12/] In Wyoming, for example, the acquisition of a water right requires application to the state engineer for a permit. Adjudication of water rights is a function of the Board of Control, consisting of the state engineer, and the water division superintendents. The distribution of water according to priority of right is a function of the division superintendents and district commissioners, headed by the state engineer. Appeals of any decisions made by these control groups lie to the courts. The Colorado procedure provides for judicially supervised allocations of rights and stated priorities with the office of the State Engineer having general supervisory responsibility.

While the specific administrative process varies from state-to-state there are common features. Each state contains some agency responsible for administering surface water rights. This agency has direct responsibility for receiving and processing applications and/or filings as well as safeguarding current rights. The agency is also responsible for assuring the delivery of reservoir or imported water to the appropriator.

Generally, the statutes address the administration of direct use of natural flow and of stored or imported water separately, and more recently have made provision for administration in the development of ground water separate from or in conjunction with surface waters. In this latter regard, ground water is generally classified as definite underground streams and percolating waters. With respect to appropriation procedures, North Dakota has dropped the distinction and provides for the appropriation of both surface and ground water. In the remaining Northern Great Plains states the distinction

has been maintained but Nebraska has no general ground water allocation statute in existence.[13/] Montana has adopted a prior appropriation law for ground water in which "any person claiming a right to withdraw ground waters or the administrator of the Montana Water Resources Board may initiate hearings to ascertain the existing rights in the area involved. At this hearing, the administrator may modify or confirm the boundaries of the area, determine priority of rights, and define quantitatively the extent of all rights being there considered."[14/] The administrator may also designate certain areas as controlled ground water areas, in which permits must be obtained to initiate appropriations.

In North Dakota, "percolating ground water is subject to a permit system of prior appropriation."[15/] In addition, the ground water code provides a statement of preferred use in the case of conflicts in use. Domestic and livestock use are preferred over irrigation and industrial use which have preference over outdoor recreational use.

South Dakota has a system of prior appropriation, which is publicly regulated, in which any person claims a vested right based on prior use files this claim with the Water Resources Commission. Subsequent to the legislation, appropriations follow the procedures for appropriation of surface water.

Wyoming has adopted a prior appropriation system applicable to all ground water in which (following March 1, 1958) the acquisition of ground water rights requires the receipt of a permit from the state engineer. For beneficial uses, the permit is granted as a matter of course if the means of diversion and construction are adequate and unless the area is designated as a critical ground water area.[16/]

In the mountain states, Arizona has held that "ground water" is subject to the rule of reasonable use rather than to appropriation. However, there is

some uncertainty and apparent contradiction in court rulings regarding ground water. Where ground water exists in definite underground channels, it is subject to appropriation. Evidently, any ground waters not confined to definite underground channels are considered to belong to the owners of the land, and are not subject to appropriation.[17/] In Colorado, ground waters in designated ground water basins and those tributary to surface water courses are subject to appropriation. New Mexico and Utah both tend to use of the appropriation framework in ground water use.[18/]

Interstate Compacts

A second major constraint which is important to the question of water available for coal and oil shale development is the existence of the various interstate water compacts, international treaties and decrees of the U.S. Supreme Court. While the appropriation doctrine has been applied on an intrastate basis it has not been found acceptable in dealing with interstate waters. There is some logic to this. States housing the headwaters and substantial portions of interstate rivers and streams may have comparative disadvantages in climate, growing season and industrial activities. They are understandably reluctant to lose the potential for growth in the future through acquisition of prior water rights elsewhere. In cases involving conflicts over interstate waters, and a mutual dependence of the states involved on a continued supply of water for present or future development, the controversies have been resolved through U.S. Supreme Court decrees or interstate compacts.

The major interstate compact affecting the state of Montana is the Yellowstone River Compact. Montana, together with North Dakota and Wyoming, comprise the membership for the Compact, ratified in December of 1950. The Compact serves as the means for allocating and appropriating the waters of the Yellowstone River System among the three states. It is administered by a

commission consisting of one representative from the U.S. Geological Survey and one representative from each state. The Compact specifically exempts that part of the Yellowstone Basin which lies within Yellowstone Park and also specifies that water rights on the Yellowstone and its tributaries perfected prior to 1950, are not subject to the terms of the compact. Diversions of water outside the Yellowstone Basin are precluded unless the three states unanimously endorse such diversion. The unused and unappropriated waters of the Yellowstone Basin are apportioned in: (1) the Clarks Fork, 60 percent to Wyoming, 40 percent to Montana; (2) the Big Horn River (excluding the Little Big Horn), 80 percent to Wyoming, 20 percent to Montana; (3) the Tongue River, 40 percent to Wyoming, 60 percent to Montana; and (4) the Powder River (including the Little Powder River), 42 percent to Wyoming, 58 percent to Montana. In addition, the Compact provides that the signatory state will not take actions which negatively affect Indian water rights to waters of the Yellowstone or its tributaries.[19/]

North Dakota is a party to the Yellowstone River Compact as is Wyoming. In Wyoming two court decrees, in addition to three interstate compacts, affect the Missouri River Basin. The court decrees are applicable to the Laramie River and the North Platte River. The former stipulates that Colorado is limited to annual diversions of 49,375 acre-feet from the Laramie River and Wyoming users are entitled to divert the remainder of the flow of the Laramie and tributaries. Colorado is enjoined from diverting more than 19,875 acre-feet from the basin for use in other parts of the state with the remaining 29,500 acre-feet to be used within the basin. No more than 18,000 acre-feet may be diverted, in Colorado, after July 31, in any year.[20/]

The North Platte Decree stipulates that Colorado may divert enough water from the North Platte River and its tributaries to irrigate 145,000 acres of land in Jackson County, Colorado, annually. Storage rights in Glendo Reservoir are limited to 40,000 acre-feet annually and would never exceed 100,000 acre-feet. This water is to be distributed among Wyoming and Nebraska with 15,000 acre-feet available for use in Wyoming below Guernsey Dam and 25,000 acre-feet available for use in Nebraska. Out of basin diversions are limited to no more than 60,000 acre-feet in any ten consecutive years. Wyoming is prohibited from diverting water above Guernsey Reservoir or from tributaries of the North Platte above Pathfinder Dam for the irrigation of more than 168,000 acres in Wyoming in any single irrigation season. Wyoming may not store in excess of 18,000 acre-feet annually for use above Pathfinder Reservoir. The natural flow of the river, between the Guernsey and Tri-State Dams, is divided on the basis of 25 percent to Wyoming and 75 percent to Nebraska between May 1, and September 30, of any year.[21/]

In addition to these decrees, and to the Yellowstone River Compact, are two other interstate compacts of interest here. These are the Upper Niobrara Compact, concerning the state of Wyoming and Nebraska, and the Belle Fourche River Compact between Wyoming and South Dakota.

The Upper Niobrara Compact includes the Niobrara River and its tributaries west of Harrison, Nebraska, and in Wyoming. Under the terms of the Compact, direct flow rights with priority dates subsequent to August 1, 1957, on the main stem of the Niobrara below Silver Springs Creek and on Van Tassell Creek from "about four miles north of Van Tassell shall be regulated in priority with rights west of Harrison, Nebraska."[22/] Domestic and stock reservoirs constructed after this 1957 date are limited in capacity to 20 acre-feet. Storage reservoirs on the mainstream, with priority subsequent to August, 1957, are limited

to a 500 acre-foot capacity. Storage reservoirs are limited to one fill per year and storage may be made only during the period October 1, to June 1, or as water is available after other direct flow appropriation in Wyoming and Nebraska have been satisfied. Provision is also made for the appropriation of ground waters in the basin between the two states, in cooperation and conjunction with the U.S. Geological Survey.

The Belle Fourche Compact between Wyoming and South Dakota recognizes all existing rights in Wyoming as of 1944, and stipulates that Wyoming may deplete the flow an additional 10 percent. Wyoming is permitted unlimited use for stock watering reservoirs with capacities up to 20 acre-feet. The compact limits the reservoirs for use of water in Wyoming alone to a capacity of 1,000 acre-feet each.[23/]

The coal and oil shale producing regions of the Rocky Mountain States are also subject to several major institutional agreements concerning water use. The first of these is the Colorado River Compact of 1922, considered to be the cornerstone of the body of law regulating the Colorado River. This compact divides the Colorado River Basin into two sub-basins at Lee Ferry, Arizona. The two basins, the Upper Basin and the Lower Basin, are each granted exclusive beneficial consumptive use of 7.5 million acre-feet (maf) per year from the Colorado River System. Additionally, the Compact specifies that the Upper Basin states must ensure that the river flow at Lee Ferry be at least equal to 75 maf in any consecutive ten year period.

The 1922 Compact has been the subject of wide disagreement and debate primarily because of the static quantity of water (75 maf in any consecutive 10 years) specified for delivery to the Lower Basin states. The provisions of the Compact were based on the flow during the period 1909-1920. The estimated annual virgin flow of the Colorado during this period (at Lee Ferry) was in

excess of 18 maf. However, the estimated flow of the river has declined markedly since 1920 and for the period 1953-1962 the average annual flow was only 11.9 maf. The Upper Basin allotment changes with each new estimate of annual virgin flow while the Lower Basin allotment remains constant.

The 1922 Compact did not allocate the Upper Basin allotment among the member states. To accomplish this allocation, the Upper Colorado River Basin Compact of 1948 was drafted and adopted in 1949. This Compact specifies that Arizona is to receive no more than 50,000 acre-feet per year as its share of water. The rest of the Upper Basin states are given a percentage of the remaining annual quantity apportioned to the Upper Basin by the Colorado River Compact. Under the Upper Basin Compact, Colorado is to receive 51.75%; New Mexico, 11.25%; Utah, 23.0%; and Wyoming, 14.0%.[24/]

The Boulder Canyon Act (Dec. 21, 1928, c. 42, 45 Stat. 1057) which authorized the construction of Hoover Dam and the All-American Canal, contained a provision stating that the project would be constructed only if California would agree irrevocably to limit its consumptive use to 4.4 million acre-feet (45 U.S.C. 1058, sec. 4). The Act also authorized agreement among the states affected by the Act on a suggested basis of 4.4 maf to California, .8 maf to Arizona, and .3 maf to Nevada. While an interstate compact never emerged, the suggested apportionment in the Act was supported in the 1963 Supreme Court decision, Arizona vs. California, et. al. (377 U.S. 546, 83 Sup. Court, 1968, 10 L. Ed. 2n 542 [1963]). The Act also authorized the Secretary of Interior to investigate and report on the feasibility of projects for irrigation, power, and other purposes in the basin. In 1946, a report entitled <u>The Colorado River</u> (H.D. 418, 80th Congress, 1st Session, 1947), provided a comprehensive view of 132 potential projects for the Colorado River. This report provided a basis for compact negotiations among the Upper Basin states which resulted in the previously mentioned Upper Colorado River Basin Compact.

Federal Constraints to Water Resource Development

In addition to state laws, court decrees,and interstate compacts governing the development and allocation of water are federal government provisions relating to development. The powers of the government are limited by the constitution and include two broad categories: federal constitutional provisions and federal statutory provisions.

Federal constitutional provisions include: (a) commerce clause, providing federal control over navigable waters, flood protection, water shed development, and recovery of costs through the production and sale of hydroelectric power. Implicit control over non-navigable streams, when the flow of such streams is required to maintain navigation capacity, is also vested in the federal government; (b) property clause, which permits the government to control and reserve water in navigable and non-navigable waterways which cross or abut lands reserved for federal purposes; (c) general welfare clause, which allows the congress to use large-scale reclamation, irrigation or other internal projects to promote the general welfare; (d) treaty clause, which, subject to the Constitution, authorizes the President to make treaties with the advice and consent of the senate; (e) supreme court, which has the constitutional authority to adjudicate water rights between the states. An example of Federal provision for the development of water supplies is given by the Upper Colorado River Storage Project Act (April 11, 1956, c 203, 70 Stat. 107) which authorized construction of 4 large storage reservoirs (Lake Powell, Flaming Gorge, Blue Mesa, and Navajo) among other reclamation projects. These reservoirs provide a combined storage capacity in excess of 24 maf and allow regulation of the flow at Lee Ferry. In addition, flood waters that previously flowed to the lower basin states can now be captured for use in the upper basin.

An important example of the treaty clause as an influence and constraint to water use and development decisions is the Mexican Treaty on the Rio Grande, Tijuana and Colorado Rivers (U.S.C. 994.59 stat. 1219, 1945). This treaty, ratified by the U.S. Senate on April 18, 1945, guaranteed to Mexico a quantity of 1.5 maf per year from the Colorado River. This quantity could be increased to 1.7 maf in surplus years and reduced in proportion to the reduction of consumptive use in the U.S. during years of extreme drought.

The treaty was a source of conflict for the upper basin states. These states maintained that the obligation to Mexico was the responsibility of the federal government and not the states. This obligation was acknowledged by the federal government in the Colorado River Basin Project Act, 1968 (82 U.S.C., 885, sec. 202).

The problem of quality of water delivered to Mexico was not handled in the treaty. Increasing consumption of water in the U.S. has resulted in decreasing the quality of water delivered to Mexico. Following 1960, the water reaching Mexico was too saline for irrigating most crops. In 1973 (Minute 242, International Boundary Waters Commission, August 30, 1973, T.I.A.'s 7708) the U.S. agreed to deliver water of a specified quality to Mexico. However, no mechanisms exist for regulating water quality and no standards for allocation of allowable degradation among the states have been agreed upon. The obligation to maintain water quality, whether state or federal, poses special problems. Particularly, in the upper basin states a large portion of the river's salt load induced by human activities is caused by irrigation return flows. The upper basin states fear that mechanisms adopted to control salinity will prevent the development of their share of Colorado River waters. At present, the issues remain, though the EPA, under the 1972 Water Quality Amendments (PL92-500) is preparing standards for reducing salinity in the river.

As an interim measure, additional releases are being made to Mexico to dilute salinity concentrations.

The federal statutory provisions cover: (a) Indian lands and waters, administered by the Bureau of Indian Affairs. The rights to lands and waters are vested with Indians; (b) irrigation of public and private lands. The original Reclamation Act of 1902 was amended by the Reclamation Project Act of 1939. This amendment authorized, in addition to planning and construction of projects for impounding and diverting irrigation water, the impoundment and diversion of water for power generation, municipal and industrial uses, recreation, fish and wildlife, stream regulation and pollution control, and if approved by the Corps of Engineers, facilities for flood control and navigation; (c) the production and sale of electric power in connection with reclamation projects. The Federal Power Act vests the Federal Power Commission with jurisdiction over the transmission and sale of electric power in interstate commerce and with jurisdiction over the public utilities involved; and (d) navigation.

An example of the statutory provisions which may have a constraining effect on water development in the two regions is the provision for Indian water rights. In 1903, the U.S. Supreme Court, in what is known as the Winters Doctrine, held that the establishment of Indian reservations was sufficient to reserve water to supply all Indian lands.[25/] This decision has made Indian land holdings an important, but as yet uncertain, element in any plans to develop remaining or unused water.

Environmental Constraints With Regard to Water

In response to deteriorating water quality in the nation's inland and coastal waters, the federal government passed on October 18, 1972, the "Federal Water Pollution Control Act Amendment of 1972." The Act focused on the following broad set of goals and policies:

1. It is the national goal that the discharge of pollutants into navigable waters be eliminated by 1985.
2. It is the national goal that wherever attainable an interim goal of water quality which provides for the protection and propagation of fish, and wildlife, and provides for recreation in and on water be achieved by July 1, 1983.
3. It is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited

In order to implement these objectives the Administrator of the Environmental Protection Agency is required to publish effluent guidelines. These guidelines would then be used to construct permit effluent limitations which restrict the discharge of residuals from industrial and other point sources. Although the focus of this procedure is on the restricting of effluents, the limitations are related to available technologies. The Act sets two deadlines for the achievement of the limitations. By July 1, 1977, industrial sources[26/] must achieve effluent limitations which require the application of the "best practical control technology currently available." By July 1, 1978, they must achieve effluent limitations which require the application of the "best available technology economically achievable." These effluent limits are supplemented with the requirement that all streams have definite minimum acceptable quality levels established (Section 303). Hence, the effluent limits for permits are a combination of technology based and water quality based limitations.

Environmental Constraints With Regard to Air

Congress in December of 1970 empowered the Environmental Protection Agency to establish natural ambient air quality standards (Section 109); standards for new stationary sources NSPS (Section 111); and national emissions standards for hazardous air pollutants (Section 112).

The ambient standards promulgated by EPA were of two forms: health related (primary) originally to be achieved by 1975, and welfare related, i.e., material, vegetation, visibility, etc. (to be achieved as quickly as

possible). The new source performance standards restrict emissions from activities that may endanger public health and welfare. Much like the technology based water standards, this standard must reflect "the degree of emission limitation achievable through application of the best system of emission reduction which (taking into account the cost of achieving such reduction) the Administrator determines has been adequately demonstrated." Emission standards for the following hazardous[27/] pollutants have been established: asbestos, beryllium, and mercury. However, none of these limitations appear to impact the operation of fuel conversion activities.

Other Environmental Factors Which May Constrain Extraction and Processing of Energy

EPA in 1973 proposed regulations which attempt to define significant deterioration in air quality and formulate procedures designed to prevent such deterioration. The issue of nondeterioration arose from a 1967 law whose stated purpose was to "protect and enhance air quality." The courts acting on a suit brought by the Sierra Club, interpreted that language to require preventive action as well. Because of the legal wrangling that followed this decision, Congress decided to clarify the issue through the legislative process. This resulted in Senate and House Bills S.3219 and H.R. 10498, respectively. These versions of the nondeterioration legislation are similar although differing in some minor details. Both specify the amount of increases allowed for pollutants in clean-air areas. The House bill covers all six pollutants while the Senate bill encompases only two, particulates and SO_2. The Senate bill divides the clean-air regions into two categories; Class I and Class II. The most carefully protected areas, Class I, are the national parks and national wilderness areas larger than 5,000 acres.

Enforcement of pollution limits in these clean-air areas would be the charge of the individual states. Enforcement would be accomplished through the control of construction permits for any new pollution source which emits more than 100 tons of any pollutant per year. In order to obtain a permit the proposed plant would have to adopt the "best available technology" to minimize emissions. Critics of the legislation argue that the extent of the Class I areas in the Northern Great Plains may preclude development of many of the area's energy deposits. Partly in response to these concerns the former Administrator for EPA, Russell Train, proposed a Class III or limited variance option. According to Train, "added flexibility to accommodate the major concentrated development that may be desired in the long run in certain areas would be provided--consistent with the existing air quality standards--by a Class III or limited variance option."[28/]

The result of this struggle between environmentalists and the energy processing industry over nondeterioration should turn out to be a most important constraint to the development of Northern Great Plains coal fields. Just as important, any significant clamp down on the air side of the problem will have some feedback onto the water side. The air/water tradeoff has been shown to exist in a number of industrial processes and most probably will prove to be present in energy extraction and processing as well.

CHAPTER II FOOTNOTES

6/ Wells A. Hutchins, Water Rights Laws in the Nineteen Western States. Completed by H. H. Ellis and J. Peter DeBraal. Volume II, Miscellaneous Publication No. 1205, NRED, ERS, USDA, Washington, D.C., 1974.

7/ Wells A. Hutchins, Water Rights Laws in the Nineteen Western States. Completed by Harold H. Ellis and J. Peter DeBraal. Volume II, Miscellaneous Publication No. 1206, NRED, ERS, USDA, Washington, D.C., 1974.

8/ Ibid., p. 11.

9/ Ibid., p. 13

10/ Northern Great Plains Resource Program, p. 25; Hutchins, Water Rights Laws in the Nineteen Western States, Volume I, 1971, p. 439.

11/ The word "conceptually" has been employed because the reality is that reallocation of water rights generally occurs within narrow geographic limits. Because of return flows, reuse potential does exist and a physical interdependence among users is established. Reallocation of water rights which involve a change in use, a change in point of diversion, a change in quality or a change in timing of use may thus affect parties external to those directly involved in transfer negotiations. A discrepancy between the private and social impacts of reallocation may thus emerge. Consideration of such impacts has led to less than complete flexibility of tenure.

12/ Hutchins, op. cit., Volume II, pp. 176-177.

13/ Ibid., pp. 631 and 643.

14/ Ibid., p. 643.

15/ Ibid., p. 647.

16/ Ibid., pp. 652-653.

17/ Ibid., p. 635.

18/ Ibid., pp. 646 and 652.

19/ Northern Great Plains Resource Program, op. cit., p. 29 and "Laws, Policies, and Administration Related to Water Resources Development," Vol. 3, Appendix of the Comprehensive Framework Study, Missouri River Basin, June, 1969.

20/ Comprehensive Framework Study, Volume 3, p. 214.

21/ Ibid.

22/ Ibid., p. 215.

23/ Ibid.

24/ Additional detail on these compacts is found in Upper Colorado Region Comprehensive Framework Study, Appendix III, "Legal and Institutional Environments," June 1971, Part XII and Part XV. See also N. K. Whittlesey.

25/ Gardner, 1976.

26/ A discharge is any source return flow of water such as that from cooling processes in power generation and water pumped from mine points.

27/ Hazardous refers to those effects which increase mortality or increase serious irreversible illness.

28/ Land Use Planning Reports, June 21, 1976, Vol. 4, No. 25, p. 2.

CHAPTER III

A PROFILE OF WATER USE AND AVAILABILITY IN THE NORTHERN GREAT PLAINS REGION

Introduction

The Northern Great Plains Region consisting of Montana, North and South Dakota, and Wyoming contains a land area of nearly 393,000 square miles. The Region contains a substantial amount of land, some 131,000 square miles, which is underlain by coal bearing rocks. The primary coal region in the four-state area consists of the Powder River and Williston Basins located in the eastern third of Montana, the northeast quarter of Wyoming, the western half of North Dakota, and the northwest quarter of South Dakota. The major river basins and sub-basins of the Northern Great Plains Region are shown in Figure 1 and consist of: the Missouri River above Williston; the Missouri River below Williston; the Knife; Heart; Cannonball; Grand; and the Little Missouri (all tributaries of the Upper Missouri River); Wind-Bighorn; Tongue; and Powder Rivers (all tributaries of the Yellowstone River).

The majority of the surface water which passes through the Upper Missouri Basin (above Sioux City, Iowa) originates in the mountains of Montana and Wyoming. The average annual flows of the principal rivers in the study region are summarized in Table 1.

The information presented in Table 1 is indicative of the approximate additional quantities of water available for use at 1970 levels of consumption. Thus they represent upper bounds on available supplies. However, if instream requirements are to be met, the upper limits must be revised downward. The instream requirements for the sub-basins are shown in the third column of Table 1.

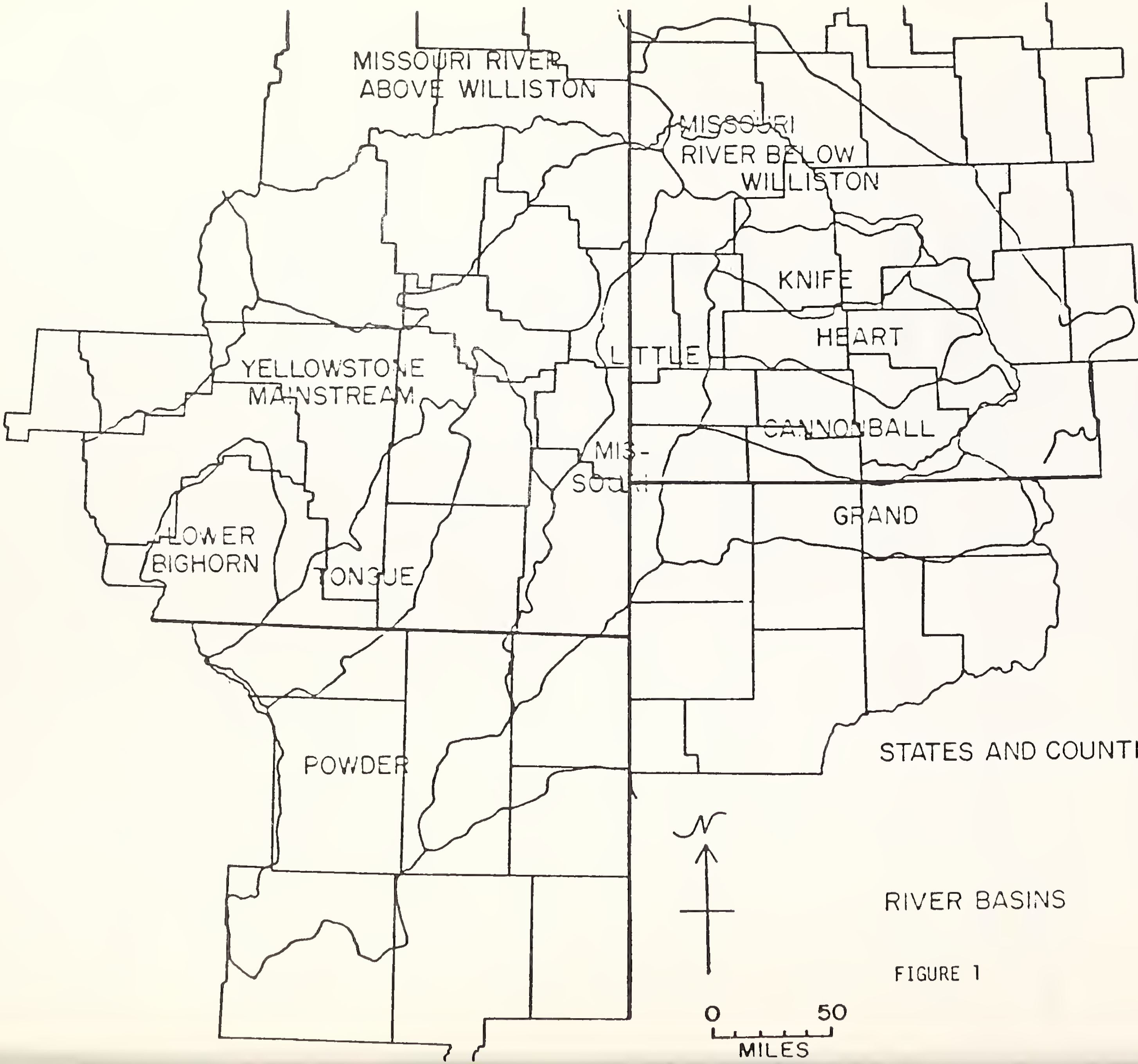
MISSOURI RIVER ABOVE WILLISTON
MISSOURI RIVER BELOW WILLISTON
KNIFE
HEART
LITTLE MISSOURI
CANNONBALL
GRAND
YELLOWSTONE MAINSTREAM
LOWER BIGHORN
TONGUE
POWDER
N
0
50
MILES
STATES AND COUNTIES
RIVER BASINS

FIGURE 1

TABLE 1

AVERAGE ANNUAL FLOW OF SURFACE WATER
REMAINING FOR USE, 1970

River	Critical Year Flow (Acre Feet)	Average Annual Flow (Acre-Feet)	Instream Requirements (Acre-Feet)
Yellowstone Basin:			
Clarks Fork	538,000	767,000	207,800
Wind Bighorn	1,429,000	2,550,000	1,527,600
Tongue	32,000	304,000	148,500
Powder	43,000	416,000	162,500
Yellowstone (near Sidney)	3,720,000	8,800,000	4,083,800
Upper Missouri Basin:			
Missouri at N.D. Border	--	7,276,000	
Missouri at Lake Sakakawea	--	16,952,000	
Missouri at Oahe Reservoir	--	18,525,000	
Western Dakota Tributaries:			
Little Missouri	35,000	390,000	184,800
Knife	3,000	118,000	61,700
Heart	17,000	154,000	70,000
Cannonball	1,000	149,000	68,300
Grand	9,000	156,000	44,800

Source: NGPRP, Water Work Group Report, Dec. 1974, p. 13.

In addition to the flows of the rivers in the region, six mainstream reservoirs, providing a total of 40.7 million acre-feet of carryover storage and 11.6 million acre-feet of seasonal joint-use storage, exist to accommodate variations in streamflow. Additionally, these reservoirs provide for 4.8 million acre-feet of dead space for flood control and 17.6 million acre-feet of inactive space for provision of power head and to accommodate future sedimentation. The total storage capacity of the mainstream reservoirs was 74.7 million acre-feet as of 1970.[29/]

The availability of ground water supplies for future water use is uncertain. Deep ground water underlies much of the coal region in the Northern Great Plains and current information suggests that ground water may represent a significant resource. However, data on quantities available for use, as well as data regarding the ability to recover the resource are insufficient to allow definitive statements on the matter. Shallow ground water supplies, perhaps adequate for certain livestock and rural domestic needs are not sufficient to provide industrial water. Surface water quality in the region is generally considered to be fair to good. Quality varies widely from location to location with the better quality water found in the mountainous regions near the headwaters. Ground water quality is subject to similar variation from location to location but much less definitive statements can be made with regard to water quality due to hydrologic and geologic problems.

The remainder of this chapter presents added detail concerning the water resources of the Northern Great Plains Region. Included in the discussion are estimates of the present availability of water in the study region; present use and remaining flows of surface water in the region for selected locations; and projected use of water in the region.

Present and Future Availability of Water

In the past it has been convenient for measurement of use, flow, and availability of surface water to follow river basins. This is unfortunate in that the geologically determined boundaries of river basins do not conform to the legal boundaries of counties or states. Therefore we are obligated to present the water data of the following sections according to river basins rather than counties or states.

In order to assess the use and availability of streamflow, six major regions within the Northern Great Plains are considered. The first four regions are each entire sub-basin (U.S. portions only) of the Missouri River Basin. These four basins are:

Upper Missouri - the Missouri River and all its tributaries above and exclusive of the Yellowstone River. The Canadian portion is excluded.

Yellowstone - the Yellowstone River and all its tributaries.

Western Dakota - all right bank tributaries of the Missouri River below the mouth of the Yellowstone and above the mouth of the Niobrara.

Eastern Dakota - all left bank tributaries of the Missouri below the Yellowstone downstream to and including the Big Sioux River.

The remaining two of the six regions are each portions of two separate river basins:

Wyoming Platte - that part of the North and South Platte River Basins which lies in Wyoming. These two rivers converge in Nebraska and later empty into the Missouri River.

Wyoming Green - the Great Divide Basin and the Wyoming portion of the Green River Basin. The Great Divide is a small closed basin, and the Green River is a tributary to the Colorado River.

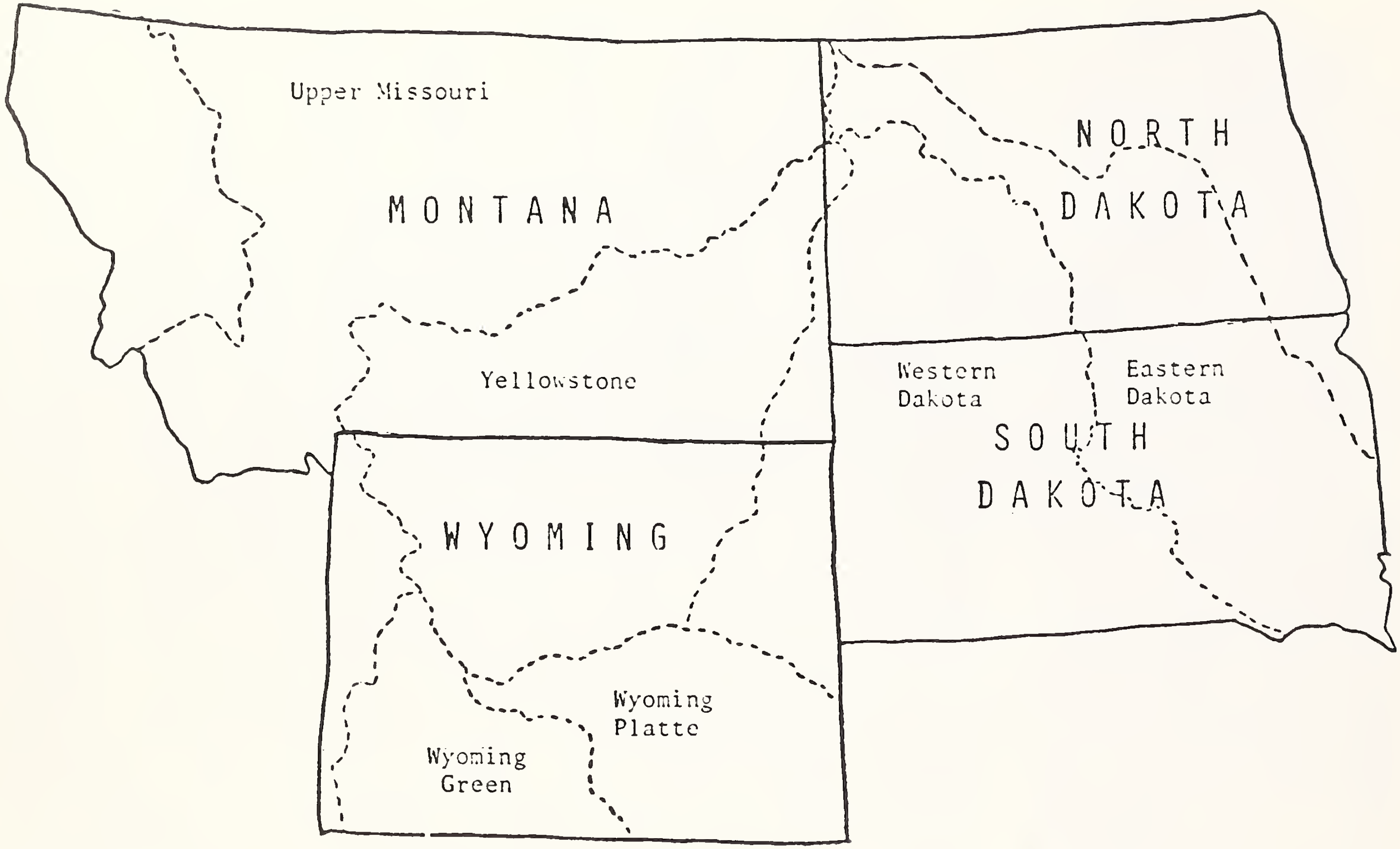

Figure 2. Study Regions for Water Availability

These six regions encompass most of the Northern Great Plains states. As shown in the study area map, the only significant exclusions are western Montana and northeastern North Dakota. Part of northeastern North Dakota is considered to be of some importance as a coal producing region.

Surface Water

Present Use and Remaining Flows

Total estimated consumption of surface water in 1970 was 7,505,200 acre-feet for the six regions. Of this amount 4,968,700 acre-feet (66.2 percent) was for irrigation, and 2,108,600 acre-feet (28.1 percent) was large reservoir evaporation. Therefore, these two uses account for more than 94 percent of the total water consumption in the Northern Great Plains. Table 2 is a breakdown (by basin) of the consumption of surface water. The Main Stem represents the segment of the Missouri River separating the Western and Eastern Dakota regions beginning at Fort Peck Reservoir. Note that evaporation from reservoirs on the Main Stem was 1,586,000 acre-feet which was 75 percent of the total large reservoir evaporation.

Included in Table 2 are the average annual remaining flows after all consumptive uses (1970) are satisfied. The remaining flows give an indication of the amount of water available for future use. Such figures must be carefully interpreted as they do not reflect the true amount of available water, that is, we cannot conclude the total remaining flows, 24,742,000 acre-feet are available to increased future use. Instream flow requirements should be maintained in order to preserve fish and wildlife, to provide recreation opportunities, to produce electricity from hydropower facilities, and to assimilate municipal and industrial pollutants. Location of future use is important since the remaining flows are not distributed uniformly throughout a basin. Seasonal variation in flows, caused by fluctuations in

TABLE 2

ESTIMATED 1970 LEVEL OF STREAMFLOW DEPLETIONS AND REMAINING AVERAGE ANNUAL FLOWS

(thousands of acre-feet per year)

	Upper Missouri	Yellowstone	Western Dakota	Eastern Dakota	Main Stem	Wyoming Platte[1]	Wyoming Green[1]	Total
Irrigation	1480.0	1987.0	426.6	256.4	0	577.1	241.6	4968.7
Large Reservoir Evaporation	168.0	99.8	43.4	5.6	1586.0	179.5[2]	26.3[2]	2108.6
Other	123.7	86.8	104.8	64.3	0	20.1	28.2	427.9
Total	1771.7	2173.6	574.8	326.3	1586.0	776.7	296.1	7505.2
Remaining Flows	7276.0	8800.0	2430.0	3235.0	--	988.2	2021.9	24,751.1

Footnotes: [1]1968 level depletions and remaining flows.
[2]Includes evaporation other than that of large reservoirs.

Sources: 1. Report on Water for Energy in the Northern Great Plains . . . , Water for Energy Management Team, U.S.D.I., January 1975.

2. Missouri River Basin Comprehensive Framework Study, Volume 6, Missouri Basin Inter-Agency Committee, June 1969.

3. The Wyoming Framework Water Plan, State Engineer's Office, Wyoming Water Planning Program, May 1973.

both precipitation runoff and water use (particularly seasonal uses such as irrigation and evaporation) must be accounted for. Other factors serve to reduce the amount of water which is consistently available: in critical years available water will be drastically reduced; rights to large amounts of water are owned but are not being exercised at present; interstate compacts restrict the use of water. Therefore it is important to evaluate the impact of the above considerations on the availability of water.

Location

Due to the importance of location in the availability of water, it is desirable to deal with smaller regions than those previously described. Therefore, we have subdivided the Yellowstone and Western Dakota basins and reduced the scope of the Wyoming Green and Wyoming Platte regions. These subdivisions are shown in Table 3, and allow us to address the problems of seasonal variations in flow, critical year flows, and instream requirements in finer detail.

The Green River Basin was reduced in size by choosing a location further upstream. The Yellowstone River Basin was divided by considering nine different locations on the Yellowstone, and its various tributaries, the Bighorn, Tongue, and Powder Rivers including the Wind River which is a tributary to the Bighorn. In the Western Dakota Basin five tributaries of the Missouri River which flow through the Fort Union Coal Region were considered. These rivers are the Little Missouri, Knife, Heart, Cannonball, and Grant. The Wyoming Platte Region was reduced by considering only the North Platte River. It was felt that neither the Upper Missouri nor the Eastern Dakota Basins warranted investigation on a smaller level since they are not expected to be major coal producing areas, and any energy development will likely divert water from the Main Stem.

The first row in Table 3 gives the gaging station number for each particular location. A gaging station is a site on a river where systematic observations of daily flow are recorded and published by the U.S. Geological Survey. The entries of the second row (where available) are the amounts of average annual remaining flows after the 1970 level of depletions.[30/] In the third row is the average yearly flow for each gaging station over the period (through 1970) in which the Geological Survey has been compiling records at each location.[31/] Although the gaging stations were established at different times, many were in operation as early as the 1930's. Since the consumptive use of water during the earlier periods of record can be expected to be much less than consumptive use in 1970, it is assumed that average annual flows after 1970 will be somewhat less than the average annual flow over the lifetime of a gaging station. Indeed, upon comparing rows 2 and 3 of Table 3 we find that for each entry in row 3, the corresponding remaining flow (row 2) is approximately 6 percent less. Using this approximation, estimated remaining flows (row 4) were generated by the following method. Where remaining flows are present in row 2 they are simply transcribed; otherwise 1970 average annual flows are reduced by 6 percent, and the resulting values are entered as estimated remaining flows. These estimated remaining flows serve as a practical upper limit to the additional use of water unless water is imported from other basins.

Seasonal Variations

For the locations being considered, seasonal variations are somewhat artificial since upstream impoundment facilities exert varying degrees of control over streamflow. Seasonal fluctuations in the flow of surface water are not absolutely due to conditions imposed by nature, and therefore it is not sufficient to analyze the seasonal variations of past years and assume

TABLE 3

REMAINING FLOWS, CRITICAL FLOWS, AND INSTREAM REQUIREMENTS AT SELECTED LOCATIONS

(in thousands of acre-feet per year)

	Wyoming	Yellowstone Basin									Western Dakota					Wyoming
	Green	Wind	Bighorn	Tongue		Powder			Yellowstone		Little Missouri	Knife	Heart	Cannon-ball	Grand	North Platte
LOCATION	near LaBarge, WY	below Boysen Reservoir, WY	near St. Xavier, MT	at state line near Decker, MT	at Miles City, MT	at Arvada, WY	at Moorhead, MT	near Locate, MT	at Miles City, MT after mouth of Tongue River	near Sidney, MT	near Watford City, N.D.	at Hazen, N.D.	near Mandan, N.D.	at Breien, N.D.	at Little Eagle, SD	at Wyoming-Nebraska State line
Gaging Station No.	2094	2590	2870	3063	3085	3170	3245	3265	3090	3295	3370	3405	3490	3540	3578	6745
Remaining Flows		960.0				185.0				8,800.0	390.0	110.0	140.0	140.0	150.0	
Average Annual Flow Through 1970	1,199.0	975.2	2,531.0	354.3	293.4	196.3	325.3	434.7	8,071.0	9,353.0	400.6	126.8	179.0	165.9	134.0	480.7 1968
Estimated Remaining Flow	1,127.1	960.0	2,379.1	333.0	275.8	185.0	305.8	408.6	7,586.7	8,800.0	390.0	110.0	140.0	140.0	150.0	451.9
Critical Year Flow	565.3 1961	550.2 1961	978.5 1966	152.2 1961	48.8 1961	65.4 1961	98.6 1961	71.5 1961	4,920.0 1960*	4,797.0 1961*	62.0 1961	19.8 1961	17.0 1961	7.4 1961	29.7 1961	292.0 1961
Instream Requirement	691.1		1,537.2	171.1	148.5	77.2	128.7	162.5	4,271.1	4,083.8	184.8	61.7	70.0	68.3	44.8	

* In 1934, flows at these two locations were lower than these values by about 14 percent; however, due to the impact of impoundment facilities constructed since 1934, those values were discarded.

Sources: 1. U.S.G.S. Surface Water Records.
2. Missouri River Basin Comprehensive Framework Study
3. NGPRP Water Work Group Report.

those same variations will prevail in the future. To do so underestimates the capacity of current structural facilities for smoothing out seasonal fluctuations. However, although the desirability of considering seasonal variations is recognized, they are omitted from present discussion.

Critical Years

As previously stated, the water supply during critical years may be drastically reduced. Overallocation of water resources can result in severe shortages during low flow years. In order to obtain an approximation of water flow during a critical year, all past surface records for each gaging station were surveyed to find the lowest recorded water flow. The results and the corresponding years are tabulated in the fifth row of Table 3. There are, however, some important exclusions from these figures which should be recognized.

Instream Requirements

The instream requirements appearing in the final row of Table 3 were calculated from data provided in the NGPRP Water Work Group Report.[32/] The Instream Needs Subgroup of the Water Work Group approximated the instream needs for certain stretches of selected rivers in the Northern Great Plains. The subgroup defined instream needs as " . . . the minimum amounts of water required in a stream (seasonally) to maintain essentially the existing aquatic resources and associated wildlife and riparian habitat".[33/] For each river segment the subgroup computed the average monthly flow (cfs) that should be maintained to satisfy the instream requirements of each month. Although their statistical methodology[34/] was rather arbitrary (as they point out), the data furnished by the Instream Needs Subgroup are the best currently available.

As stated, the subgroup established average monthly flows for each of the twelve months at each location. In Table 3 these values were converted to units of acre-feet per year. In order to legitimize this conversion it must be assumed that the value representing acre-feet per year is flowing at the precise monthly rates established by the Instream Needs Subgroup; therefore, the instream requirements appearing in Table 3 are the minimum yearly amounts of water necessary to meet the instream flows specified by the subgroup.

Availability

The information on estimated remaining flows indicates that large quantities of water in excess of instream requirements are available for increased future use. Even in the Knife River Basin, which has the least remaining flows of any location included in Table 3, over 48,000 acre-feet of water is available in an average year after accommodating instream requirements and present uses. Nearly 100 times that amount is available from the Yellowstone River at Sidney, Montana, where another 4,716,200 acre-feet per year is available. Between these two extremes we see that water is abundant at all locations in significant quantities to support varying degrees of energy development. Water available from the Yellowstone River is enough to supply the needs of hundreds of coal-fired electric generation plants. Therefore, in the average year water is available in magnitudes large enough to support any and all conceivable energy needs.

This picture is less optimistic, however, if critical year flows are compared to instream requirements. With two exceptions (both on the Yellowstone River), critical year flows cannot adequately satisfy instream requirements. It must be recognized, however, that the methodology used by the Instream Needs Subgroup of the NGPRP allowed for instream requirements not to be met

during periods of extremely low flows. In fact, the methodology anticipated that instream requirements would exceed critical flows. Therefore, in the face of expanding energy production, instream requirements may be neglected during periods of shortages.

Interstate Compacts

Constraints imposed by the interstate compacts have been discussed and do not require reiteration; however, Wyoming has estimated its allotments of water subject to the Yellowstone and Upper Colorado River Compacts. These allotments are presented in Table 4.[35/]

Table 4

Wyoming's Legal Entitlement to Water
(thousands of acre-feet per year)

Bighorn River	1800	After supplemental water is supplied to pre-1950 Wyoming water rights.
Tongue River	96.4	
Powder River	120.7	
Belle Fourche River	7	In addition to pre-1945 water rights
Green River	875	

It is important to realize that the allotments represent quantities available in an average year and are thus subject to fluctuations. Again, critical years may seriously affect the availability of water. The following quote indicates the severity of drought years. "Water supply studies showed that if a drought year such as 1961 reoccurs, Wyoming's allocation in that year would be little, if any, in either the Tongue River or Powder River."[36/]

In the Green River Basin the level of total water use was 409,000 acre-feet per annum in 1965, thus leaving 396,000 acre-feet per year (805,000 minus

409,000) for increased future use after satisfying the terms of the Upper Colorado River Basin Compact.

Quality

Water quality determines whether or not the resource is suitable for man's use in any alternative. Quality indicators exist in physical, chemical, and biological characteristics with the first two receiving the primary thrust in the Northern Great Plains Region.

While quality measurements are somewhat limited in the Region, existing indications are that water quality of surface flows is generally fair to good with variation between locations. As noted early in this chapter, the surface water supplies in the Northern Great Plains originate in the higher elevations of Montana and Wyoming. Stream quality at the heads of streams in these mountainous areas is excellent. Quality in terms of the physical, chemical and biological characteristics generally deteriorates downstream due to natural forces (hydrologic and geologic) and man's use. In most locations within the study region, quality is satisfactory for withdrawal uses such as irrigation, livestock, municipal and industrial purposes, and for instream use for recreation and fish and wildlife. Water quality data for the Northern Great Plains have been summarized in the NGPRP Water Work Group Report (p. 14) and this summary is reproduced in Table 5. It will be noted that variations in water quality do exist. For example, the mineral quality of water is high in the Yellowstone River with total dissolved solids averaging 460 mg/l and ranging from 230 mg/l to 655 mg/l. In the Powder River at Moorehead, Montana total dissolved solids average 1,552mg/l and range from 676 mg/l to 4,080 mg/l. The Belle Fourche at the Wyoming-South Dakota border averages 1,190 mg/l with a range from 428 mg/l to 2,450 mg/l.

Table 5
WATER QUALITY SUMMARY 1/

	Temp C	DO mg/l	BOD mg/l	pH units	Flow cfs	TDS mg/l	SS mg/l	T-NO_3 as N mg/l	NH_3 mg/l	T-PO_4 as P mg/l	Pb ug/l	Cu ug/l	Hg ug/l	F ug/l	Se ug/l	Al ug/l	B ug/l	Zn ug/l
Bighorn River at Bighorn, Montana																		
No. of samples	81			275	343	32	47							70			57	
Maximum value	27.2			8.5	23000	836	21100							700			270	
Minimum value	0.0			7.0	612	471	42							200			30	
Mean value	112.8			7.7	4249	608	4088							400			133.5	
Period of record	59-73			59-73	49-73	68-73	59-71							59-73			49-73	
Tongue River at Miles City, Montana																		
No. of samples	35			236	260	34		11						62			50	
Maximum value	29.4			8.8	4139	816		.1						800			1250	
Minimum value	0.0			6.9	16	262		.01						20			10	
Mean value	10.5			7.9	594	560		.04						361			137.3	
Period of record	66-73			59-73	59-73	68-73		69-70						62-73			62-73	
Powder River at Moorhead, Montana																		
No. of samples	62	33	34	34	55	1/	-	-	31	30	9	9	7	10	7	-	6	8
Maximum value	28.5	12.4	10.0	8.5	4600	4080	-	-	0.61	3.20	5.0	30.0	0.9	2200	11.0	-	448.0	32.0
Minimum value	0.0	5.2	0.6	7.4	8	676	-	-	0.00	0.0	0.0	0.0	0.0	0.0	0.0	-	241.0	0.0
Mean value	10.5	9.0	3.0	8.0	642	1552	-	-	0.09	0.54	1.0	10.4	0.2	500	3.7	-	274.8	16
Period of record	69-72	69-72	69-72	69-72	69-72	69-72	-	-	69-72	69-72	69-72	69-72	70-72	69-72	70-72	-	69-72	69-72
Yellowstone River at Sidney, Montana																		
No. of samples	97	18	18	311	375	37	24	23	25	41	4	4		83		4	79	4
Maximum value	24.4	12.6	3.3	8.9	65240	655	15500	.69	.26	2.7	0	10		800		200	260	0
Minimum value	0	7.4	.9	6.9	1149	230	167	0.0	0.0	.01	0	0		100		100	20	0
Mean value	11.3	9.8	1.8	7.8	14527	460	2308	.2	.06	.32	0	2.5		449		150	146.4	0
Period of record	65-73	70-73	70-73	59-73	59-73	68-73	65-72	69-70	69-72	69-73	66	66		59-73		66	54-72	66
Knife River at Golden Valley, N.D.																		
No. of samples	51			107	140	105	30	105	43	2		1		107			107	1
Maximum value	23.9			8.6	9620	2700	3340	9.3	9.3	.58		40		900			1200	20
Minimum value	0			6.6	.2	114	66	.2	.7	.05		40		100			50	20
Mean value	9.6			7.8	340	1004	1201	2.31	3.85	.32		40		456			257.5	20
Period of record	63-73			63-73	63-73	63-73	63-65	63-73	64-65	65-72		1965		63-73			63-73	1965

Table 5. Water Quality Summary--continued

	Temp C	DO mg/1	BOD mg/1	pH units	Flow cfs	TDS mg/1	SS mg/1	T-NO$_3$ as N mg/1	NH$_3$ mg/1	T-PO$_4$ as P mg/1	Pb ug/1	Cu ug/1	Hg ug/1	F ug/1	Se ug/1	Al ug/1	B ug/1	Zn ug/1
Heart River at Mandan, N.D.																		
No. of samples	63	63	63	63		60				26								
Maximum value	25	16.2	8.9	9.0		2280				.76								
Minimum value	0	3.7	.8	7.0		175				.01								
Mean value	10.3	9.6	2.9	8.0		844				.11								
Period of record	68-73	68-73	68-73	68-73		68-73				71-73								
Cannonball River at Breien, N.D.																		
No. of samples	25			26	26	26		6		16				26			25	
Maximum value	24			8.3	2770	1960		4.8		.21				1400			860	
Minimum value	0			7.2	15	285		1.0		0				100			0	
Mean value	10.2			7.8	414	1139		2.68		.02				546			346	
Period of record	70-72			70-72	70-72	70-72		70-72		71-72				70-72			70-72	
Missouri River at Bismarck, N.D.																		
No. of samples	797	400	346	653	581	360			288	24	16	16		11	2	13	15	16
Maximum value	22	14.3	6.0	8.6	36400	653			.9	.07	60	50		700	.1	59	360	42
Minimum value	0	6.1	0	7.7	1040	268			0	.01	4	10		450	.01	9	91	2
Mean value	8.3	10.6	1.1	8.3	18239	425			.24	.04	33.6	22		519	.2	37.3	217	20.4
Period of record	57-73	58-73	58-73	57-72	57-66	58-73			58-66	65-69	62-71	62-71		63-68	62-63	63-71	63-71	63-71
Belle Fourche at Wyoming-South Dakota border																		
No. of samples	55	13	12	193	182	121	2	69	8	8	7	7	6	182	8	2	188	6
Maximum value	28.3	12.7	4.2	8.6	917	2450	510	4.10	.75	.88	40	14.0	.5	1100	70	90	470	140
Minimum value	0.0	7.5	.8	6.6	3	428	218	0.0	0.0	.02	1.0	2.0	.2	70	0	57	0	10
Mean value	10.8	9.7	1.7	7.8	111	1190	364	.58	.14	.35	12.6	4.7	.3	770	13.9	73.5	158.4	56.7
Period of record	60-73	70-73	70-73	60-73	60-73	67-73	60	67-71	70-72	70-72	70-72	70-72	70-72	60-73	70-72	70-71	60-73	70-72
Cheyenne River near Wasta, South Dakota																		
No. of samples	23	10	10	16	22			10	10	10	4	4		4			4	4
Maximum value	27	14	20	9.5	1150	2060		1.8	.78	5.9	3	37		1400			274	28
Minimum value	0	6.2	.9	7.5	6	350		0	0	.07	0	0		400			123	0
Mean value	8.6	10.7	3.6	8.1	654	1066		7.8	.78	.35	.8	9.6		800			218	16.8
Period of record	69-70	69-70	69-70	69-70	69-70	55-57		69-70	69-70	69-70	69-70	69-70		69-70			69-70	69-70

1/ See Glossary for explanation of column headings.

Source: NGPRP Water Work Group Report, Table 2.

Concentration of suspended solids also varies widely from one location to another. For example, the Belle Fourche River at the Wyoming-South Dakota border averages 364 mg/l while the Bighorn River at Bighorn, Montana averages 4,088 mg/l. In addition, seasonal variation in suspended solids concentration exists.

While water quality is generally acceptable, the analysis of the impacts of any particular development requires that locational and seasonal variations in water quality be taken into account.

Groundwater

In the four states comprising the Northern Great Plains, groundwater withdrawals vary from 2 percent to 58 percent of total water use withdrawals.[37/] Montana, with 2 percent, is the second lowest in the conterminous United States while South Dakota, with 58 percent, is the fifth highest. Respectively, Wyoming and North Dakota have groundwater withdrawals of 4 percent and 14 percent of total water withdrawals. This wide range of groundwater utilization, which is very sensitive to the relative availabilities of surface water, gives an indication of the differing surface water pictures in the separate states. Indeed, the extensive supply of water lying beneath the earth serves as a nearly perfect substitute (depending on quality) to the use of streamflow. The underground aquifers in which this water is stored may be viewed as natural reservoirs. In contrast with man-made reservoirs, evaporation from aquifers is negligible.

Although the existing groundwater supply appears to be quite large, it is depletable. The amount of water that may be pumped from a given aquifer without depleting the groundwater supply is determined by the net recharge rate of that aquifer. The recharge rate is the amount of water

per unit of time that enters the aquifer from neighboring aquifers or streams. When withdrawals exceed that recharge rate, the groundwater resource is being mined. Mining of groundwater is justifiable provided such mining does not surpass the safe economic yield [38/] of the aquifer.

Utilization of groundwater has both advantages and disadvantages over the use of surface water. One definite advantage is that groundwater is widely available in time, space, quantity, and quality. A well can be drilled in almost any location, and it will constantly yield water in some amount and quality. However, the same cannot be said for surface water since streamflow is spatially limited and subject to extreme fluctuations in availability.

The invisible nature of the groundwater resource creates a handicap in that extensive geologic and hydrologic studies must be performed in order to assess the quantities of water available. In the absence of such studies, growth in groundwater use can only proceed with uncertainty since the limits of groundwater supplies would not be known. This could easily result in over-development causing excessive pumping costs and dry wells. The need for hydrologic investigations is further emphasized by the interdependent relationship between surface and groundwater supplies. As an aquifer becomes depleted, water is induced to flow into the aquifer from nearby streams and aquifers. Therefore, groundwater use is interrelated with surface water use, and this relationship is variable depending upon the hydrologic nature of the aquifer and surrounding areas.

An important advantage of groundwater use is that groundwater supplies have no direct habitat value. However, indirect habitat value may be substantial due to potential streamflow leakages into groundwater aquifers. Therefore, if surface-groundwater interrelationships are minor, ground-

water can be developed without concern for consequential losses of wildlife and aquatic ecosystems.

Other disadvantages associated with groundwater development are disruption by strip mining and land subsidence. Strip mining introduces a low pressure area within the groundwater system, thereby inducing groundwater flows into the mine. This leakage reduces groundwater supplies and deteriorates water quality.[39/] Land subsidence may occur because of mining of the groundwater supply. As groundwater levels fall, the drained levels of an aquifer may compact causing the overlying land surface to sink.[40/] Resulting structural damage can be considerable.

Availability of Groundwater

Appraising the quantities of groundwater available to support future energy development necessitates the aforementioned hydrologic and geologic investigations. Groundwater underlying the Northern Great Plains appears to be partitioned into two vague aquifer classifications: shallow aquifers and deep aquifers. Shallow aquifers, because of their slight depth and heavy utilization, are relatively well known. On the other hand, use and exploration of deep aquifers has been preempted by the relatively inexpensive access of shallow aquifers. Consequently, we assess separately the ability of these two aquifer types to supply water for large scale energy development.

Shallow Aquifers

Table 6 gives the approximate amounts of water stored in the shallow aquifers of each of the six regions.[41/] However, economic extraction of the total groundwater supply is not feasible. Therefore, these figures are upper limits of the economically available supplies. Although Table 6

indicates the availability of massive supplies, shallow groundwater aquifers do not possess the potential to sustain the extensive long-term pumpage that would be required to serve the local needs of energy production. Furthermore, shallow aquifers and surface water flows are very interdependent, so large scale shallow groundwater withdrawals would undoubtedly deplete streamflow.

Table 6

SHALLOW GROUNDWATER IN STORAGE
(acre-feet)

Upper Missouri	9,000,000
Yellowstone	15,000,000
Western Dakota	231,000,000
Eastern Dakota	604,000,000
Wyoming Green	700,000
Wyoming Platte	3,200,000

Of critical importance is the fact that shallow aquifers are heavily utilized in many areas of the Northern Great Plains for livestock, irrigation, municipal and rural domestic purposes. Present users would raise harsh objections to further development by energy sectors since they would be adversely affected by substantial increases in groundwater withdrawals. Also, interference caused by strip mining will decrease supplies.

The above considerations virtually cancel the shallow aquifer potential to support the needs of energy expansion. If groundwater is to be available, then it must originate from the deep aquifers.

Deep Aquifers

Recent interests concerning the availability of deep groundwater have focused on some geologic formations called the Madison Group which underly much of the four Northern Great Plains states. Primary attention has been in the Powder River Basin of Montana and Wyoming: it is in this basin that

surface water shortages have been severe and coal development is most intensive. The Madison Group is the upper layer of the major aquifer in the Powder River Basin.[42/] At its deepest location the top of the Madison is more than 10,000 feet below sea level or about 16,000 feet below the earth's surface.[43/]

The Madison Group and associated rocks are the potential source of extensive supplies of groundwater. However, costs are usually prohibitive because of the required well depths. The high cost of drilling very deep wells presents an advantage in that competing usage is quite small allowing deep groundwater development to occur without the full inhibition which would accompany similar shallow aquifer development. In 1973 use of Madison groundwater was only about 28,600 acre-feet in the Powder River Basin and the Black Hills.[44/]

Unfortunately, data concerning the supply of water available from the Madison is quite deficient. Recharge into the Madison is yet unknown but is suspected to be small. Therefore, major development will probably result in mining of the groundwater resource.[45/] Although approximations of the deep groundwater supply, recharge, and safe economic yield are not yet established, we may introduce the advantages and problems relating to deep groundwater development. One disadvantage, high costs; and two advantages, large supply and low usage, have already been mentioned. One unproven disadvantage, low recharge, has also been cited.

In contrast with surface water resources Madison water is widely available throughout the region and has little aesthetic value. Also, unlike shallow aquifers, land subsidence will not be a major concern. These are two definite arguments in favor of using deep groundwater for future energy needs, but there are also opposing disadvantages.

Water quality is low and variable between wide limits, and, as use of Madison water expands, quality will further deteriorate.[46/] Treatment may therefore be necessary to decrease the mineralization of the water. Water temperatures are quite high (200° F to 250° F),[47/] and holding ponds will be required if the water is to be used for cooling purposes.

Also of importance is the fact that a well drilled into the Madison does not necessarily yield large quantities of water. The reason for this is as follows: "Because the primary (or intergranular) porosity of the Madison appears to be low, water is stored mostly in and transmitted through secondary openings such as fractures, joints, and solution openings. The occurrence of these secondary openings is quite variable and difficult to predict, which may explain the wide range in yields of water wells drilled into the Madison."[48/] Besides uncertainty of well yield, hydrologic factors introduce an additional complication. If in a particular locale, deep groundwater is to be heavily developed, wells would interfere with one another by increasing pumping lifts. Therefore, wells should be sited as far apart as possible in order to minimize such negative effects.[49/]

Lack of information regarding the hydrologic setting within and about the Madison Group prohibits a valid appraisal of the amount of groundwater available from these sources. Although costs of a well field tapping the Madison for certain amounts of water may be and have been roughly approximated,[50/] the length of time such pumping rates can be sustained is unknown. If the Madison is to provide substantial quantities of water for energy development during an extended period, then such knowledge is mandatory. Recently, the U.S. Geological Survey has begun research to acquire the needed information.[51/] Until the relevant stages of this research are completed, only very rough approximations can be made.

In a recent study [52] concerning the feasibility of a proposed well field to be used to supply water for a planned slurry pipeline, the outlook was pessimistic. The proposal is to withdraw 15,000 acre-feet per year from the Madison underlying eastern Niobrara County, Wyoming, for a period of fifty years. Because of the inadequate data base, assumptions had to be made, but even under ideal conditions the study showed that within twenty years ground-water levels would decline to the extent as to make the project infeasible. Naturally, at other locations the Madison will respond differently, but this study does exhibit the finite potential of the Madison Group and the necessity for complete investigations.

Projected Use

A necessary step in determining the availability of surface water for future energy development is the projection of other water uses. Table 7 is the consolidation of two separate studies [53] which have projected water consumption in 1980, 2000, and 2020. Note that entries of this table are not aggregate levels of water consumption but are levels of consumption above 1970 depletive uses.

Total increases in surface water depletions for all six regions are estimated to be in excess of 1,816,600; 3,853,400; and 6,409,800 acre-feet per year, respectively, in 1980, 2000, and 2020. Projected increases in large reservoir evaporation were unavailable for the Wyoming Platte and Wyoming Green regions. However, as is usually the case, irrigation can be expected to account for the bulk of consumption. It is anticipated that irrigation will be responsible for an increasing proportion of total water use. This is supported by the projections for 1980, 2000, and 2020, which show irrigation to account for 66 percent, 76 percent, and 79 percent,

TABLE 7

PROJECTED AVERAGE ANNUAL DEPLETIONS OF WATER FOR NON-COAL AND NON-OIL SHALE USES

(above 1970 level)

	Upper Missouri[1]	Yellowstone[1]	Western Dakota	Eastern Dakota[2]	Wyoming Platte[3]	Wyoming Green[3]	Total
1980							
Irrigation	305.0	325.9	215.0	224.6	52.4	70.6	1,194.5
Large Reservoir Evaporation	31.7	11.0	1.0	82.1	NA	NA	125.8+
Other	26.1	228.6	115.0	111.8	3.9	10.9	496.3
TOTAL	363.8	565.5	331.0	418.5	56.3+	81.5+	1,816.6+
2000							
Irrigation	628.2	786.1	455.0	803.4	118.3	139.3	2,930.3
Large Reservoir Evaporation	70.0	21.7	28.0	95.3	NA	NA	215.0+
Other	91.9	147.2	242.0	184.6	10.2	32.2	708.1
TOTAL	790.1	955.0	725.0	1,083.3	128.5+	171.5+	3,853.4+
2020							
Irrigation	821.7	1,097.6	818.0	1,910.6	268.7	146.3	5,062.9
Large Reservoir Evaporation	77.6	62.1	30.0	99.8	NA	NA	269.5+
Other	45.8	245.5	364.0	365.7	11.1	45.3	1,077.4
TOTAL	945.1	1,405.2	1,212.0	2,375.1	279.8+	191.6+	6,409.8+

[1] Includes expected gains from precipitation management.

[2] Includes expected diversions from the Main Stem (primarily for irrigation).

[3] Above 1968 level.

Sources: 1. Missouri River Basin Comprehensive Framework Study, Volume 6, December, 1971. Hydrologic Appendix, pp. 130-132.

2. The Wyoming Framework Water Plan, State Engineer's Office, Wyoming Water Planning Program, May, 1973, pp. 84 and 95.

respectively, of total increased depletions. The primary factor allowing for this increased irrigation is future diversion of water from the Main Stem for use in the Dakotas. Looking at the remaining flows of Eastern Dakota (Table 2), it appears quite doubtful that Eastern Dakota could sustain such increases in total water consumption without large-scale diversions from the Missouri.

Comparing Tables 2 and 7, the remaining flows for each region are in excess of the projected increase in depletions.

It can be concluded that average annual remaining flows can satisfy even the 2020 projections and ample water would remain for use by energy sectors. When instream requirements (where given) are considered, ample water would still be available. For example, over three million acre-feet per year would be unemployed in the Yellowstone Basin after satisfying instream requirements and projected depletions.

Increasing the Available Water Supply

In the event that water will be unavailable to support certain levels of future energy development, it will become desirable to employ methods that will expand the real (usable) supply of water. It is the purpose of this section to present these alternatives but not to approximate their costs nor to evaluate in detail the magnitude of water that can be made available.

Storage Potential

In the Northern Great Plains there exist many suitable sites for the construction of reservoirs which serve to increase the consistent supply of water although some water is lost through increased evaporation. In addition, reservoirs may provide flood protection, recreation and hydropower.

Table 8 is a partial inventory of potential reservoirs with some corresponding pertinent data. Included are reservoir names, the rivers upon which they are located, and the points at which water conserved by the reservoirs would be diverted. Active capacity and flood space requests are given for each reservoir or group of reservoirs; flood space requests, if granted,[54/] reduce active capacity since that space must remain unused in case of above normal runoff. The final columns of Table 8 show water availability during critical years for four different cases. The water availability figures represent gross water quantities that can be supplied by each reservoir or group of reservoirs. These quantities of water are not generally attributable solely to reservoirs since some water is constantly available without reservoir construction.

According to the NGPRP Water Work Group Report,[55/] an additional two million acre-feet of water could be available annually in the Yellowstone Basin if enough new storage is constructed and if instream needs are fully met. If instream requirements are reduced by 90 percent then three million acre-feet would be available in addition to present supplies. Obtaining these levels of water supply would necessitate extensive and costly construction.

A major problem incurred by increasing the supply of water with storage facilities is that of environmental damage. Depending on location, the environmental disturbances produced by a reservoir may be very large. Needless to say, this will be the source of much opposition; and, therefore, the viability of large-scale reservoir construction as a possible alternative is somewhat uncertain.

Interbasin Water Transfers

Interbasin water reallocation via aqueducts possesses a large potential to supply or supplement water in locations of scarcity. In most cases, such

Table 8

POTENTIAL STORAGE INVENTORY

(thousands of acre-feet per year)

Reservoir	River	Diversion Point	(1,000 acre-feet) Active Capacity	Flood Space Requests	Water Available During Critical Years: After Instream A[2]	Providing Requirements B[2]	Providing Instream A[2]	10% of Requirements B[2]
Sunday Creek	Offstream Yellowstone	Miles City, MT	664.0	125	710	957	2,493	3,703
Tullock Creek plus above	Offstream Yellowstone	Miles City, MT	925.0	215	915	1,243	2,768	3,983
Moon Creek plus all above	Offstream Yellowstone	Miles City, MT	1,073.7	215	988	1,330	2,925	4,145
Cedar Creek plus all above	Offstream Yellowstone	Miles City, MT	1,199.8	215	1,049	1,401	3,057	4,277
Sweeney Creek plus all above	Offstream Yellowstone	Miles City, MT	1,313.8	215	1,106	1,466	3,177	4,397
Buffalo Creek plus all above	Offstream Yellowstone	Miles City, MT	1,380.5	265	1,119	1,507	3,253	4,473
Lignite Creek plus all above	Offstream Yellowstone	Miles City, MT	1,410.3	265	1,130	1,520	3,285	4,505
Lissa Creek plus all above	Yellowstone	Miles City, MT	2,225.0	1,500	1,323	1,944	3,941	5,161
Bighorn Lake[1] and Boysen[1]	Bighorn	Miles City, MT	1,918.0 [3]			484		3,349
Bighorn Lake[1] and Boysen[1]	Bighorn	Mouth of Armells Creek	1,918.0 [3]			474		3,098
Hunter Mountain	Clarks Fork	Miles City, MT	123.24	35	134	331	1,526	2,746
Thief Creek	Clarks Fork	Miles City, MT	190.0	90	204	224	1,778	2,993
Sunlight	Sunlight Creek	Miles City, MT	48.0	30	49	89	1,055	2,275
Sunlight, Thief Creek, and Hunter Mountain	(Clark Forks Basin)	Miles City, MT	361.24	155	350	572	2,147	3,367
Clarks Fork	Clarks Fork	Miles City, MT	327.0		325	520	2,084	3,304
Allenspur	Yellowstone	Miles City, MT	1,880.0 [3]	50	400	1,483	3,653	4,738
Boysen[1]	Bighorn	at reservoir	802.0 [3]			111		431
Bighorn Lake[1] and Boysen[1]	Bighorn	at Bighorn Lake	1,918.0 [3]			319		1,391
Bighorn Lake[1] and Boysen[1]	Bighorn	Hardin, MT	1,918.0 [3]			353		1,417
Custer, Bighorn Lake,[1] and Boysen[1]	Bighorn	at Custer Reservoir	2,743.0 [3]			611		1,777
North Prairie Dog	Tongue	at reservoir	9.9	9.9		15		41
Rockwood	Tongue	at New Tongue Reservoir	98.0	43		29		83
Stateline	Tongue	at reservoir	113.6	108		46		119
New Tongue	Tongue	at reservoir	180.0	133		63		159
Hole-in-the-Wall	Powder	at Pumpkin Reservoir	45.0	0		24		46
Pumpkin	Powder	at reservoir	675.0	300		32		65
Box Elder	Powder	at reservoir	53.8	8		34		34
Lower Crazy Woman	Powder	at Arvada Reservoir	425.0	75		27		62
Arvada	Powder	at Arvada Reservoir	780.0	250		65		123
Lower Clear Creek	Powder	at Moorhead Reservoir	572.0	120		101		161
Moorhead	Powder	at reservoir	525.0	250		77		129
Wagon Creek	Little Missouri	at reservoir	185.0	119		25		34
Mill Iron	Little Missouri	at reservoir	27.0	45		5		13
Marmarth	Little Missouri	at reservoir	429.0	370		26		53
Medora	Little Missouri	at reservoir	212.0	330		54		100
Beaver	Little Missouri	at reservoir	81.0	65		2		2
Broncho	Knife	at reservoir	303.8	40		17		23
Mott	Cannonball	at reservoir	223.0	85		13		21
Thunderhawk	Cannonball	at reservoir	100.0	211		12		21
Cannonball	Cannonball	at reservoir	170.0	172		22		35
Shadehill[1]	Grand	at reservoir	81.5 [3]			0		0

Footnotes:
[1] Boysen and Shadehill Reservoirs and Bighorn Lake already exist.
[2] Possibility "A" is where 1,200,000 acre-feet per year is diverted from the Bighorn River either at Bighorn Lake or at some point downstream. In such case instream requirements will not be provided from the point of diversion to the mouth of the Bighorn. In case "B" there are no Bighorn diversions.
[3] Excludes exclusive flood control space.

Source: NGPRP Water Work Group Report, Tables 4, 5a, 5b, and 5d.

aqueducts would be large, long and have high pumping heads. Current proposals involve transfers from the Green, Bighorn, and Yellowstone Rivers to locations within the Platte, Powder, and Tongue River Basins.[56/] Other possibilities include diversions from the Missouri River to the Dakotas. All pipelines would be buried in order to prevent freezing and minimize long-term environmental damage. The potential for interbasin water transfers is largely variable and dependent upon the spatial distribution of water needs relative to excess supplies although such diversions are naturally limited to water supplies available at the point of diversion. Similar to the alternative for constructing additional reservoirs, the principal factors in determining the viability of building aqueducts are economic costs and environmental consequences.

Weather Modification

Expansion of the available water supply may also be accomplished by the implementation of known weather modification techniques. Augmenting precipitation can increase the winter snowpack of mountainous regions (thereby increasing spring runoff) and decrease irrigation requirements by supplementing summer rainfall. Costs are estimated to be quite low (\$1 - \$3 per acre-foot),[57/] but many environmental, legal, and social problems have not yet been fully studied.

As indicated on footnote 1 of Table 7, gains from weather modification are expected to occur in the Upper Missouri and Yellowstone Basins.[58/] Indeed, the Missouri Basin Inter-Agency Committee[59/] has gone as far as to project additions to water supply achieved by such methods. A breakdown of these projected gains is shown in the following table:

TABLE 9

Projected Weather Modification Additions
to the Water Supply
(thousands of acre-feet per year)

	Upper Missouri	Yellowstone	Total
1980	19.6	89.0	108.6
2000	78.4	267.0	345.4
2020	196.0	536.0	732.0

As Table 9 shows, precipitation management is expected to perform a substantial role in the future availability of water. However, in order to capture the increased runoff provided by weather modification, it may be necessary to construct additional impoundment facilities. This, along with the institutional obstacles, must be solved before large-scale additions to water supplies can be realized from weather modification.

Other Alternatives

There are a few other techniques which can effect additions to the real water supply. One such method is to neglect instream requirements. By exercising control over streamflow volumes with existing and future storage facilities, water would only be released to serve the productive needs of man. Although feasible, this method is unpalatable as it would result in severe environmental damage. However, such an alternative can be practiced at certain locations where habitat values are small.[60/]

Another method of increasing the water available for future energy development is to allow energy-related industries to purchase existing water rights from other sectors. If, for example, water has a higher value in energy production than in irrigated agriculture, the reallocation of water via the market mechanism could occur naturally. Indeed, market exchange of water rights to energy sectors has already begun.[61/] However, this

alternative is not without costs because of the resulting loss of irrigated acreage. In addition to the production losses due to suspended irrigation, substantial surrenders of irrigation water may undermine local agriculturally based economies.

The preceding discussion of alternatives to increase the water supply is neither thorough nor necessarily complete. A very important aspect of these alternatives, their relative costs, has not even been touched. In the final analysis, relative costs, both economic and social, should determine which of supply increasing or demand decreasing methods will be undertaken. Furthermore, these alternatives are not mutually exclusive, and therefore the most practical alternative is a combination of some or all available techniques depending on relative costs.

CHAPTER III FOOTNOTES

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31/ 1970 Water Resources Data for Montana, North Dakota, South Dakota, and Wyoming Surface Water Records, U.S. Department of the Interior, Geological Survey, 1971.

32/ NGPRP, Water Work Group Report; Instream Needs Subgroup Report, States of Montana, Nebraska, North Dakota, South Dakota, Wyoming, and the U.S. Department of Agriculture, U.S. Department of Interior, Environmental Protection Agency, May, 1974, pp. 11-33.

33/ Ibid., p. 1.

34/ Ibid., pp. 2-9.

35/ The Wyoming Framework Water Plan, State Engineer's Office, Wyoming Water Planning Program, May, 1973, pp. 100, 101, and 108.

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37/ Water Atlas of the United States, Geraghty, Miller, Van Der Leeden, Troise, Water Information Center, Port Washington, New York, 1973, Plate 32.

38/ "Safe Yield of Aquifers: An Economic Reformulation," Robert Young, Journal of the Irrigation and Drainage Division, ASCE, Vol. 96, No. IR4, Proceedings Paper 7719, December, 1970, pp. 377-385.

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40/ Summary Appraisals of the Nation's Ground-Water Resources--Upper Colorado Region, Don Price and Ted Arrow, U.S. Geological Survey Professional Paper 813-C, 1974, p. C33.

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42/ Possible Development of Water from Madison Group and Associated Rock in Powder River Basin: Northern Great Plains Resources Program, Frank A. Swenson, July, 1974, p. 1.

43/ Plan of Study of the Hydrology of the Madison Limestone and Associated Rocks in Parts of Montana, Nebraska, North Dakota, South Dakota, and Wyoming, U.S. Geological Survey Open-File Report 75-631, December, 1973, Table 2.

44/ Ibid.

45/ Swenson, op. cit., p. 3.

46/ Ibid., p. 2; NGPRP Water Work Group Report, op. cit., p. 56.

47/ Swenson, op. cit., p. 5.

48/ Preliminary Digital Model of Ground-Water Flow in the Madison Group, Powder River Basin and Adjacent Areas, Wyoming, Montana, South Dakota, North Dakota, and Nebraska, Leonard F. Konikow, U.S. Geological Survey Water Resources Investigations 63-75, January, 1976, p. 71

49/ Swenson, op. cit., p. 3.

50/ Ibid., enclosed table.

51/ Plan of Study . . . , op. cit.

52/ "Technical Feasibility of the Proposed Energy Transportation Systems Incorporated Well Field, Niobrara County, Wyoming," Peter Huntoon and Travis Womack, Contributions to Geology, Vol. 14, No. 1, 1974.

53/ See citations following Table 7.

54/ It is assumed that they will be granted.

55/ Ibid., p. 46.

56/ Ibid., Appendix--Scenario Water Supply. Appraisal Report on Montana-Wyoming Aqueducts, Bureau of Reclamation, U.S. Department of the Interior, April 1972. The Wyoming Framework Water Plan, State Engineer's Office, Wyoming Water Planning Program, May 1973, pp. 140-149.

57/ Missouri Basin Inter-Agency Committee, op. cit., p. 118.

58/ Gains are also expected in the Platte River Basin but lack of data prevented computation of what portion of these amounts would accrue to Wyoming.

59/ Ibid., pp. 130-131.

60/ The NGPRP Water Work Group Report indicates that the Powder River Basin may be such a location.

61/ NGPRP Water Work Group Report, pp. 19-20.

CHAPTER IV

A PROFILE OF WATER USE AND AVAILABILITY IN THE ROCKY MOUNTAIN REGION

Introduction[62/]

The Rocky Mountain Region includes the states of Arizona, Colorado, New Mexico, and Utah. Total land area in the region is 424,738 square miles, some 15 percent (or 62,290 square miles) of which is underlain by coal-bearing rock. The region also contains the major deposits of oil-bearing shale. Since a portion of these deposits exists in Wyoming, it is necessary to refer to that state's water supply and use in portions of the following discussion. Six distinct river basins including the Great Basin, the Upper Colorado River Basin, the Lower Colorado River Basin, the Missouri River Basin, the Arkansas River Basin, and the Rio Grande Basin are found in the region. These basins are shown in Figure 1. The headwaters of rivers such as the Colorado, Arkansas, and Rio Grande are contained in these basins. However, the geographic location of major coal and oil shale deposits and water supplies do not necessarily coincide and, since the primary concern is, eventually,to assess the availability of water to provide for energy needs, the water resource profile will be restricted to those river basins which will most likely provide the water necessary for future increases in energy production. The basins which appear to be most relevant to future coal production are the Colorado River Basin, the Great Basin, the Missouri Basin and the Rio Grande Basin. For oil shale, the Upper Colorado River Basin is the major source of water supply. A brief description of each basin and the relevance to regional energy production follows.

FIGURE 1.

Major River Basins of the Rocky Mountain States

Colorado River Basin

The Colorado River Basin includes portions of all four of the Rocky Mountain states in addition to parts of Nevada and Wyoming. The Colorado River Basin encompasses a land area greater than that of New Mexico and Arizona combined, the nation's fifth and sixth largest states. This basin is clearly the most important of the Rocky Mountain Region. The basin, under the Colorado River Compact (1922) is divided into two segments, the upper and lower basins. Lee Ferry, a point on the Colorado a few miles into Arizona, is the designated division between the Upper and Lower Colorado River Basins. All data of the following sections will be presented according to this separation.

The Upper Colorado includes the Wyoming and Colorado portions of the Colorado River Basin, part of Utah, and small areas within Arizona and New Mexico. Major coal mining and conversion is anticipated throughout this region. The major coal deposits of the Upper Colorado Basin are the medium to highly volatile bituminous coal deposits in northeastern and central Utah and northwestern and southwestern Colorado. In addition, the Upper Colorado Basin contains deposits of subbituminous and bituminous coal in northeastern New Mexico. This basin also contains the states housing oil shale deposits of the region.

The Lower Colorado Basin, containing 135,900 square miles, contains most of Arizona and parts of Nevada, New Mexico, and Utah. In addition, the basin includes 5,200 square miles which drain directly into Mexico. The major coal production of the Lower Colorado Basin is to be found in the northeast portion of the Basin where deposits of subbituminous coal are located.

The Great Basin

The Great Basin includes most of Nevada, the western half of Utah, and small portions of the states of Wyoming and Idaho. The Basin itself is largely

a collection of basins which are closed with respect to surface water flows. Within the Rocky Mountain Region, only the southeastern portion of the Great Basin, in south-central Utah, is expected to contain significant future increases in coal production. The coal deposits in the Great Basin are of the medium-to-high-volatile bituminous coal type.

The Missouri River Basin

The only portion of the Missouri River Basin contained in the Rocky Mountain region is in northeastern quadrant of Colorado. The portion of the Missouri River Basin drained by the North Platte River possesses significant deposits of medium- and high-volatile bituminous coal available for future increased mining activity. There are additional subbituminous coal deposits within the Missouri River Basin in north central and northeastern Colorado, but these deposits lie outside the regional delineation selected by the USDA-ESCS.

The Rio Grande Basin

The Rio Grande has its headwaters in Colorado and drains most of New Mexico and parts of Texas. Only a slight portion of this basin overlaps a substantial coal deposit. Data availability prohibits delineation of the Rio Grande Basin into a region which accurately reflects the nature of water use and supplies in this small coal-bearing region. Therefore, hydrologic consideration of any portion of the Rio Grande Basin is omitted from the following text. The effect of this omission is likely to be inconsequential.

Thus, four major basins appear to constitute the potential for rapid increases in energy in the Rocky Mountain region. These four basins have been further disaggregated into eight separate subbasins, a disaggregation dictated largely by the available data on water supplies, present use, and projected future use. Three of these subbasins, the Green River, the Upper Colorado

River and the San Juan are parts of the Upper Colorado Basin. Three of them, the Lower Colorado River, the Little Colorado River and the Gila River subbasins are parts of the Lower Colorado River Basin. The Great Basin contains the seventh subbasin, the Sevier Lake basin, and the Missouri River Basin houses the eighth subbasin, that of the North Platte River. Within the Lower Colorado River Basin, the Little Colorado subbasin is currently of primary importance as a source of water. However, the two remaining subbasins will be significantly impacted by future energy development, and this warrants their inclusion. The Sevier Lake Subregion is a closed basin within the Great Basin and encompasses potential coal producing areas. As previously indicated, the North Platte is the relevant subbasin of the Missouri River Basin, and, therefore, it forms the eighth and final subregion. Only that part of the North Platte which lies in the State of Colorado is considered, and this part corresponds to Jackson County. The subbasins are shown in Figure 2.

The following discussion and presentation of data on water supplies, current depletions by use, and projections of future use are consistent with this subbasin disaggregation.

Surface Water Supplies and Use

One of the major problems created by the various institutional arrangements regulating water use in the region is some uncertainty as to how much water there actually is to be divided among users. In addition, alternative sources estimate different quantities of water available in the region. These two factors render it difficult to make authoritative statements regarding the total surface water supplies available to the region.

While an assessment of the impact of the institutional arrangements is largely beyond the scope of this report, an example of some of the results will highlight the importance of such constraints. Consider the arrangements,

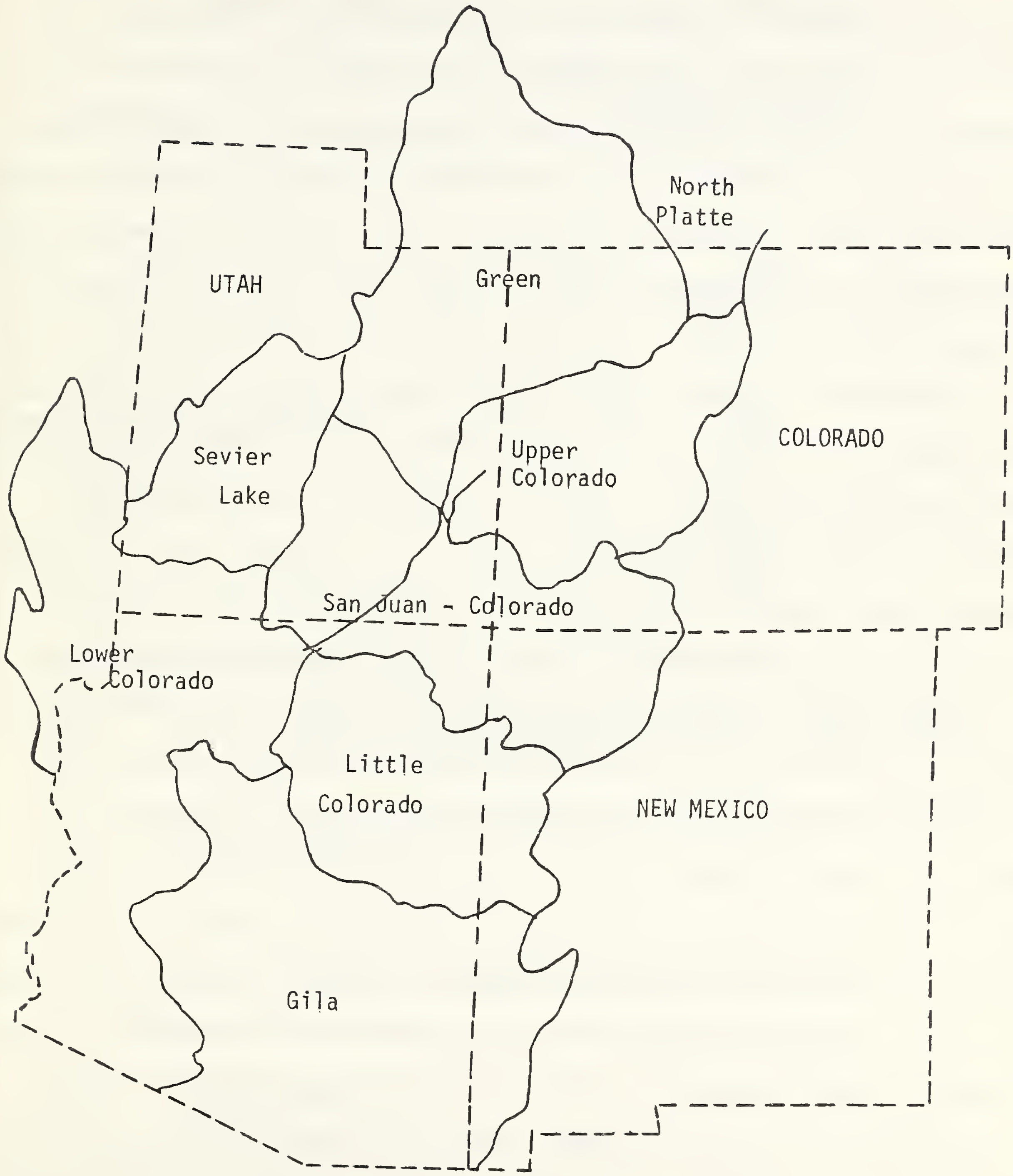


FIGURE 2.

Subregions in the Rocky Mountain States

identified in Chapter II, regulating the Colorado River. The allocation of water to all lower basin states amounts to an average of 7.5 maf per year in the original compact. In addition, the interpretation of the Mexican treaty favored by the lower basin states and the federal government would require the upper basin states to provide an additional 0.75 maf per year. Adhering to this interpretation would therefore require the upper basin states to release an average of 8.25 maf per year to the lower basin as measured at Lee Ferry.

The original division of upper and lower basin allocations was based upon an assumed 10-year average annual flow exceeding 18 maf. Table 1 provides the estimated breakdown of these surface water supplies in the Colorado Basin. However, as late as 1974 some agencies were using an assumed flow of 15 maf to estimate water supplies in the Colorado River Basin.[63/] The U.S. Bureau of Reclamation has provided estimates ranging from 13.2 maf to 15.5 maf with a value of 14.1 maf being given most probable status.[64/] Andrews, et. al.[65/] cite the Bureau of Reclamation as favoring a figure of 13.8 maf. The Lake Powell Research Group settled on a range in water yield of 13.0 - 13.5 maf and this range was adopted by Andrews. However, nature provided an average runoff of only 11.6 maf for the period 1954-1963. This divergence between estimates sets bounds on water availabilities and also makes it apparent that individual states can easily arrive at differing estimates of their own water allocations. Table 2 provides a rough breakdown of water allocation to individual upper basin states and to the lower basin states and Mexico as a group. That group will always be entitled to an allocation of 8.25 maf regardless of the yield of the river. Also Arizona is guaranteed an annual flow of 50,000

TABLE 1

SURFACE WATER SUPPLIES OF THE COLORADO RIVER BASIN

Subregion	Mean Undepleted Supplies (1,000 Acre-Feet)
Green	5,460
Upper Colorado	6,806
San Juan	2,606
Total	14,872
Lower Colorado (tributaries)	900
Little Colorado	420
Gila	1,809
Total	3,129
Colorado River Basin Total	18,001

SOURCES: 1. Upper Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, p. 59.

2. Lower Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, pp. 73, 88, 94.

TABLE 2

ESTIMATED ALLOCATION OF COLORADO RIVER WATER BASED UPON

ALTERNATIVE GROSS RIVER FLOWS -- IN MILLION ACRE FEET

Annual Flow	Lower Basin, including Arizona and Mexico	Colorado	Utah	Wyoming
18.00	8.30	5.02	2.23	1.36
15.50	8.30	3.73	1.66	1.01
14.10	8.30	3.00	1.33	0.81
13.30	8.30	2.59	1.15	0.70
11.60	8.30	1.71	0.76	0.46

acre-feet from the upper basin states allotment, making a total of 8.3 maf. While the original compact and subsequent federal interpretations tend to support this view, it is not clear that upper basin states will be so inclined, particularly if actual flows remain substantially below the 15 maf level.

Table 2 shows that Colorado claims on the Colorado River could range from 1.71-5.02 maf. Similar variability could be applied to Utah and Wyoming water allocations.

The confusion surrounding the institutional arrangements regulating water use is compounded by the variety of estimates regarding the total available supplies and current use of water in the region. Consider, for example, the information contained in Table 3, which shows an estimated breakdown of the share of Upper Colorado River Basin water supplies available to each of the oil shale states and the amounts committed for use currently and in the future.

The figures shown in this table are based upon an assumed upper basin allocation of 5.75 maf or a gross flow of about 14.0 maf if the lower basin states are given 8.25 maf. This set of figures, developed by the Department of Interior, shows Colorado with 90,000 acre-feet of water that could be devoted to coal or oil shale production. Utah and Wyoming have even larger supplies of water for this use. However, it is important to note that commitments for future water use in Colorado already exceed potential supplies by 64,000 acre-feet, implying that some future commitments or current uses will have to be reduced to supply any water to energy development. Of course, this estimate is based on an assumed Colorado share of 2.976 maf of water. According to Table 1, the most probable supply of water for Colorado would be 2.59 maf based upon current estimates of total flow equaling 13.3 maf. This difference of more than 300,000 acre-feet could cut severely into future water use plans in Colorado. Note also that Utah has a reduction of about 160,000 acre-feet of water if the lower estimate of Colorado River flow is accepted.

TABLE 3

PRESENT AND FUTURE WATER USE IN THE UPPER COLORADO RIVER BASIN

(THOUSAND ACRE-FEET PER YEAR)

	Colorado	Utah	Wyoming	Total
State share of 5,750,000 acre-feet 1/	2,976	1,322	805	5,103
1974 Use	-1,855	- 705	-328	-2,888
Committed Future Use	- 916	- 381	-371	-1,668
Evaporation from Storage Units	- 269	- 120	- 73	- 462
Not Identified as to Use	- 64	116	33	85
Committed future use that could be made available for oil shale	154 2/	12 3/	200 4/	366
Total potential water that could be made available for depletion for development	90 6/	128	233	451

1/ Arizona received the right to the consumptive use of 50,000 acre-feet per year.

2/ From the existing Green Mountain and Ruedi Reservoirs and the authorized West Divide Project.

3/ From the authorized Jensen, Upalco, and Uintah Units.

4/ From the existing Fontenelle Reservoir - Seedskadee Project.

5/ This includes water not presently identified for a particular use, plus water from authorized projects committed to oil shale development and water from existing reservoirs not presently committed to a particular use. Additional water can be made available if the States permit the industry to purchase some of the water rights from those presently using water and if the use category is changed from some of the future commitments.

6/ The water committed to future use that could be made available to oil shale (154,000 A/F) would be reduced to 90,000 A/F only if apparent over commitment of 64,000 A/F is removed from those committed uses that could provide water for oil shale. It is possible that other committed future uses will not develop as indicated or that a higher priority may be given to oil shale development. In that event, it would be possible that additional water could be made available for oil shale or other industrial uses.

Source: USDI, Report on Water for Energy in the Upper Colorado River Basin. Water for Energy Management Team. July 1974.

To illustrate the potential confusion created by these figures we can observe recent claims of water supply in Utah and Colorado. The state of Utah generally takes a liberal view of its claim on Colorado River water, placing it at 1.4 maf [66/] and claims the unused portion of Utah's share to be 600,000 acre-feet. Felix L. Sparks, Director of the Colorado Water Conservation Board, describes an environmental impact statement on the potential Colony Development as understating the uncommitted water available for oil shale development at 160,000 acre-feet. He says, "there (are) at least 800,000 acre-feet of water available to Colorado on an annual basis which is not now being used," and at least 250,000 acre-feet could be made available to oil shale development. Sparks believes this to be "true under the most restrictive interpretations of the available allocations under the interstate compacts and Mexican water treaty.." [67/]

In both Colorado and Utah there are conditional water decrees awarding the use of water which exceed even the state's estimates of current surpluses. However, this water has not yet been put to beneficial use and, therefore, could be devoted to energy development. There are, for example, seven authorized Bureau of Reclamation projects in Western Colorado which have not yet been constructed. The total depletion for these seven projects is estimated at 450,000 acre-feet. Some of the water in these projects is planned for energy development, however.

Glenn[68/] provides a rather complete accounting of water use in the upper basin states. His estimates of current consumption, shown in Table 4, agree with those of the USDI. However, Glenn properly charges the upper basin

TABLE 4

ESTIMATED 1974 UPPER COLORADO RIVER BASIN DEPLETIONS

(1,000 ACRE-FEET)

	Arizona	Colorado	Utah	Wyoming	New Mexico	Total
Thermal Powerplants	1/	9	1	3	25	38
Food and Fiber (Irrigation)	10	1,255	529	258	102	2,153
Fish, Wildlife, and Recreation 2/	3	31	24	16	6	80
Minerals and Mining		17	9	18	4	48
Livestock Ponds and Evaporation		21	6	3/ 21	4/ 31	79
Municipal and Industrial		18	6	3	8	35
Exports		504	130	10	110	754
Coal-Gasification						
Oil Shale						
Subtotal	13	1,855	905	328	286	3,187
Main Stem Reservoir Losses	0	269	120	73	58	520
Total Depletion	13	2,124	825	401	344	3,707

1/ First unit of Navajo Powerplant went online in May of 1974. Actual depletion amount not available.

2/ Natural historic wildlife consumption not included.

3/ Includes evaporation from Fontenelle Reservoir.

4/ Includes evaporation from Navajo Reservoir.

Source: Glenn, Water Availability to Meet Future Competing Demands in the Upper Colorado River and Upper Missouri River Basins. Paper presented at the Western Resources Conference, Fort Collins, Colorado, July 1976.

states with their share of main stem reservoir losses. These evaporation losses amount to 269,000 acre-feet for Colorado and 120,000 acre-feet for Utah.

Table 5 presents the estimated depletion by type of use and by state for each of the Rocky Mountain States and Wyoming. There are some minor differences in the total depletion for the Upper Basin shown in Tables 4 and 5. However, the difference is 9,000 acre-feet, which is insignificant in terms of the total depletions.

Projected Use in Relation to Estimated Supply

Table 6 presents present and projected depletions by river basin, state and irrigation and other use. This information does not include any projected changes in energy needs and thus the relationship between present and future depletions and total supply estimates give an estimate of the water available for future energy development if other projected uses actually take place. Projections for the North Platte subregion are not yet available, but the present level of depletion can be expected to continue without diminishing. The most probable situation is that total depletions for this subregion will increase and thus the estimated total future depletion is likely to be a lower bound to what may actually occur.

It is clear from Table 6 that depletion levels will generally increase in the future with some exceptions in the Lower Colorado Region. The reason for declining depletion in this region is that as depletions increase in the Upper Colorado Region, water supplies to the Lower Colorado will decrease. Some of the pressure on Lower Basin supplies can be reduced, however, by decreasing the depletions in the Lower Colorado Main Stem. Although not shown in Table 6, the decrease in Lower Colorado Main Stem depletion can be accomplished largely by reducing exports to California.[69/]

Table 5

DEPLETIONS BY TYPE AND STATE

(1000 AF/yr)

Region	State	Municipal & Industrial	Thermal Electric	Min-erals	Fish & Wildlife	Recre-ation	Irri-gation	Evap-oration	Live-stock	Net Export	Other	Total
Upper Colorado (1974-76)	Arizona	3.0	12.0	0	0	0	10.0	0	0	0	0	25.0
	Colorado	18.0	9.0	17.0	3.2	.8	1255.0	269.0	21.0	504.0	0	2097.0
	New Mexico	8.0	25.0	4.0	4.2	1.1	90.7	58.0	5.0	136.0	0	332.0
	Utah	6.0	1.0	9.0	23.5	.9	538.6	120.0	6.0	130.0	0	835.0
	Wyoming	3.0	3.0	18.0	5.5	10.9	264.6	73.0	21.0	10.0	0	409.0
	Total	38.0	50.0	48.0	36.4	13.7	2158.9	520.0	53.0	780.0	0	3698.0
Lower Colorado (1965)	Arizona	161.6	6.8	50.0	79.6	2.7	4913.4	202.9	----	----	0	5417.0
	Nevada	30.3	2.8	.6	30.0	.8	174.3	12.1	----	----	0	250.9
	New Mexico	3.6	0	.9	.7	.1	71.6	12.0	----	----	0	88.9
	Utah	2.4	0	0	0	0	66.2	3.4	----	1.3	0	73.3
	Main Stem	0	0	0	0	0	0	1200.0	0	5000.0	1310.0	7510.0
	Total	197.9	9.6	51.5	110.3	3.6	5225.5	1430.4	0	5001.3	1310.0	133[illegible]
Sevier Lake	Utah (1965)	7.0	0	1.0	55.0	1.0	600.0	70.0	----	-9.1	237.0	961.9
North Platte	Colorado (1970)	----	----	----	----	----	108.0	----	----	22.0	2.0	132.0
All Above Regions	Arizona	164.6	18.8	50.0	79.6	2.7	4923.4	202.9	0	0	0	5442.0
	Colorado	18.0	9.0	17.0	3.2	.8	1363.0	269.0	21.0	526.0	2.0	2229.0
	New Mexico	11.6	25.0	4.9	4.9	1.2	162.3	70.0	5.0	136.0	0	420.9
	Utah	15.4	1.0	10.0	78.5	1.9	1204.8	193.4	6.0	122.2	237.0	1870.2
	Lower Main Stem	0	0	0	0	0	0	1200.0	0	5000.0	1310.0	7510.0
	TOTAL	209.6	53.8	81.9	166.2	6.6	7653.5	1935.3	32.0	5784.2	1549.0	17472.1

SOURCES:

1. Upper Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, p. 40.
2. Lower Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, pp. 33, 34, 45.
3. Colorado State Water Plan, Phase I - Appraisal Report, Bureau of Reclamation, State of Colorado, February 1974, p. 3.3.
4. Report on Water for Energy in the Upper Colorado River Basin, U.S. Department of the Interior, Water for Energy Management Team, July 1974, p. 13.
5. Projected Water Supply and Depletion, Upper Colorado River Basin, Bureau of Reclamation, August 1976.
6. Great Basin Region Comprehensive Framework Study, Appendix V. Water Resources, June 1971, pp. 25, 88.

Table 6

PRESENT AND PROJECTED DEPLETIONS BY TYPE AND STATE

EXCLUDING CHANGES IN ENERGY NEEDS

(1000 AF/yr)

Region	State	1965			1980			2000			2020		
		Irri-gation	Other	Total	Irri-gation	Other	Total	Irri-gation	Other	Total	Irri-gation	Other	Total
Upper Colorado (1974-76)	Arizona	10.0	15.0	25.0	10.0	40.0	50.0	10.0	40.0	50.0	10.0	40.0	50.0
	Colorado	1,255.0	842.0	2,097.0	1,391.1	1,045.0	2,436.1	1,778.2	1,299.7	3,077.9	1,754.5	1,327.2	3,081.7
	New Mexico	90.7	241.3	332.0	245.0	221.5	466.5	411.0	228.3	639.3	411.0	244.6	655.6
	Utah	538.6	296.4	835.0	576.6	358.0	934.0	660.6	440.0	1,104.6	695.2	462.0	1,157.2
	Wyoming	264.6	144.4	409.0	334.0	187.1	521.1	407.0	274.7	681.7	427.1	314.1	741.2
	Total	2,158.9	1,539.1	3,698.0	2,556.7	1,851.6	4,408.3	3,266.8	2,286.7	5,553.5	3,297.8	2,387.0	5,685.7
Lower Colorado	Arizona	4,913.4	503.6	5,417.0	5,596.0	643.6	6,239.6	4,937.0	913.3	5,850.3	5,011.0	1,423.4	6,434.4
	Nevada	174.3	76.6	250.9	193.0	159.9	352.9	185.0	328.8	513.8	180.0	484.6	664.6
	New Mexico	71.6	17.3	88.9	99.0	27.4	126.4	110.0	45.5	155.5	101.0	63.7	164.7
	Utah	66.2	7.1	73.3	78.0	23.2	101.2	80.0	24.2	104.2	89.0	26.0	115.0
	Main Stem	0	7,510.0	7,510.0	0	6,510.0	6,510.0	0	6,140.0	6,140.0	0	6,140.0	6,140.0
	Total	5,225.5	8,114.6	13,340.1	5,966.0	7,364.1	13,330.1	5,312.0	7,451.8	12,763.8	5,381.0	8,137.7	13,518.0
Sevier Lake	Utah	600.0	361.9	961.9	618.0	349.9	967.9	663.0	344.9	1,007.9	710.0	346.9	1,056.9
North Platte	Colorado (1970)	108.0	24.0	132.0	108.0	24.0	132.0	108.0	24.0	132.0	108.0	24.0	132.0
All Above Regions	Arizona	4,923.4	518.6	5,442.0	5,606.0	683.6	6,289.6	4,947.0	953.3	5,900.0	5,021.0	1,463.4	6,484.4
	Colorado	1,363.0	886.0	2,229.0	1,391.1+	1,045.0+	2,436.1+	1,778.2+	1,299.7+	3,077.9+	1,754.5+	1,327.2+	3,081.7
	New Mexico	162.3	258.6	420.9	344.0	248.9	592.9	521.0	273.8	794.8	512.0	308.3	820.3
	Utah	1,204.8	665.4	1,870.2	1,272.6	731.1	2,003.7	1,403.6	813.1	2,216.7	1,494.2	834.9	2,329.1
	Lower Main Stem	0	7,510.0	7,510.0	0	6,510.0	6,510.0	0	6,140.0	6,140.0	0	6,140.0	6,140.0
	TOTAL	7,653.5	9,818.6	17,472.1	8,721.7	9,242.6	17,964.3	8,757.8	9,503.9	18,261.7	8,889.7	10,097.8	18,987.5

SOURCES:
1. Upper Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, pp. 40, 58.
2. Lower Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, pp. 33-40. 45.
3. Colorado State Water Plan, Phase I - Appraisal Report. Bureau of Reclamation, State of Colorado, February 1974, p. 3.3.
4. Great Basin Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971. pp. 25. 88.
5. Projected Water Supply and Depletions, Upper Colorado River Basin, Bureau of Reclamation, August 1976.

Future Water Availability

Estimating the future availability of surface water for potential energy development is a tenuous business because of institutionally imposed uncertainties, varying estimates of use (present and projected), and varying estimates of available supplies.

In order to assess the future availability of surface water for proposed energy development, it is necessary to combine the pictures of existing supplies and projected depletions that have been developed for the eight subregions. Since essentially three distinct river basins are being dealt with, the following estimates of future availability will appear in three parts. The first concerns the extremely important Colorado River Basin, and the latter two will consider the Sevier Lake Subregion and the North Platte River Subregion.

Present and projected average conditions in the Colorado River Basin are illustrated in Table 7. This table represents depletions of the Colorado River Basin in relation to supplies. Institutional factors such as the Colorado River Compact, the Mexican Treaty, and the Upper Colorado River Basin Compact are neglected.

The first row is the mean undepleted surface water supply of the entire Upper Colorado River Basin. The subsequent five rows give the individual state depletion levels within the Upper Colorado Region. When these depletions are subtracted from the supply, the residual represents outflow at the compact point, Lee Ferry. Adding surface water supplies originating within the Lower Colorado River Region yields the total surface water supply available to the lower basin states. Subtracting state depletions results in the remaining flow of the Colorado River into Mexico.

The most striking feature of Table 7 is the negative flows to Mexico in 2000 and 2020. Of course, this is impossible, yet it does provide ample

substantiation that the Colorado River will be unable to support future levels of development. The estimated availability of water shown in Table 7 is really quite optimistic. In the first place, the assessment of gross flows in the upper basin of 14.872 million acre-feet is well in excess of other estimates cited previously in this chapter. If, for example, a natural flow of approximately 13.3 million acre-feet in the Colorado River is maintained in the future, some striking differences in the results of Table 7 would be noted. Table 8 shows these differences.

Table 8 shows that if actual supplies are 13.3 million acre-feet rather than 14.9 million acre-feet assumed in Table 7, not only is there insufficient water to meet the requirements of the Mexican Treaty, but also insufficient water to meet the needs of the Lower Colorado Basin. Also, Table 7 indicates that none of the upper basin states would experience a water shortage through the year 2020. However, under the assumed flow of 13.3 maf in Table 8, the outflow of 8.25 maf from the upper basin to the lower basin will not be met in the year 2000. Even under the optimistic estimates of flow in Table 7, if residual outflow at Lee Ferry was reduced to 8.25 maf and if the outflow to Mexico were increased to satisfy the 1.5 maf in the Mexican Treaty, the lower basin states would have to reduce current water consumption by 3.46 maf and substantially reduce future growth. The projected deficits in the lower basin states in Table 7, or the current deficits in Table 8, will be primarily financed through mining of available ground water supplies.[70]

The material presented in Tables 7 and 8 contain projections which are based on past trends in water use and not on any specific plans for water use

Table 7

COLORADO RIVER BASIN SUMMARY

(1000 acre-feet per year)

	Present	1980	2000	2020
Upper Colorado Virgin Supply	14,872	14,872	14,872	14,872
Less: Arizona Depletions	25	50	50	50
Colorado Depletions	2,097	2,436	3,078	3,082
New Mexico Depletions	332	467	639	656
Utah Depletions	835	935	1,105	1,157
Wyoming Depletions	409	521	682	741
Residual Outflow (Lee Ferry)	11,174	10,463	9,318	9,186
Plus: Virgin Supply Originating in the Lower Colorado Basin	3,129	3,129	3,129	3,129
Lower Colorado Water Supply	14,303	13,592	12,447	12,315
Less: Arizona Depletions	5,417	6,240	5,850	6,434
Nevada Depletions	251	353	514	665
New Mexico Depletions	89	126	156	165
Utah Depletions	72	101	104	115
Main Stem Depletions	7,510	6,510	6,140	6,140
Residual Outflow	964	262	-317	-1,204

TABLE 8

COLORADO RIVER SUMMARY (A)

(1000 ACRE-FEET PER YEAR)

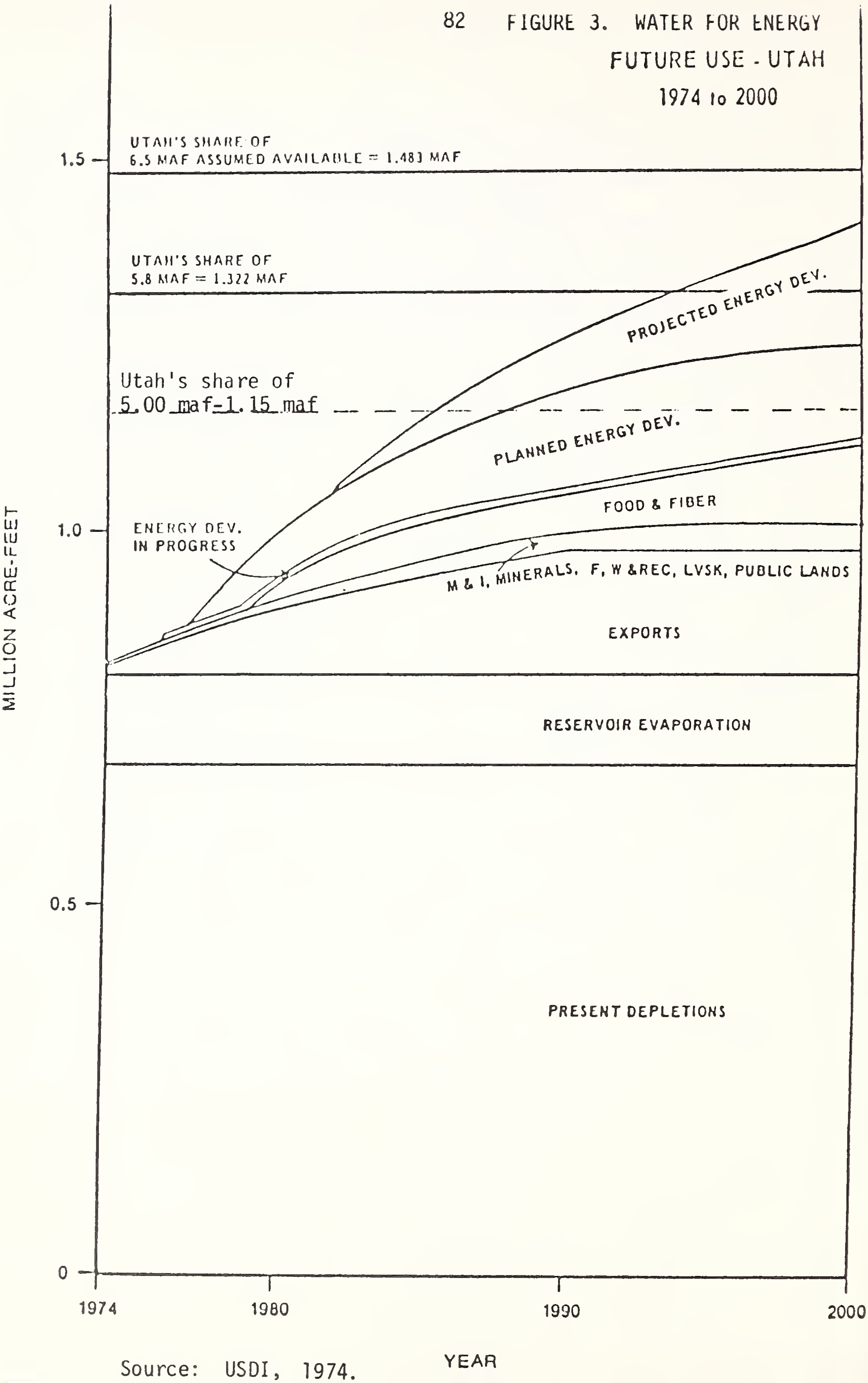
	Present	1980	2000	2020
Upper Colorado Virgin Supply	13,300	13,300	13,300	13,300
Less: Arizona Depletions	25	50	50	50
Colorado Depletions	2,097	2,436	3,078	3,082
New Mexico Depletions	332	467	639	656
Utah Depletions	835	935	1,105	1,157
Wyoming Depletions	409	521	682	741
Residual Outflow (Lee Ferry)	9,602	8,891	7,746	7,614
Plus: Virgin Supply in the Lower Colorado Basin	3,129	3,129	3,129	3,129
Lower Colorado River Supply	12,731	12,020	10,875	10,743
Less: Arizona Depletions	5,417	6,240	5,850	6,434
Nevada Depletions	251	353	514	665
New Mexico Depletions	89	126	156	165
Utah Depletions	72	101	104	115
Main Stem Depletions	7,510	6,510	6,140	6,140
Residual Outflow	- 608	- 1,310	- 1,889	- 2,776

in energy, agriculture, municipal, etc. Glenn [71/] projects water use rates which are higher than those projected in Tables 7 and 8. These higher use rates serve to hasten the arrival of water deficits in Colorado and Utah and to compound the deficits problem in the Lower Basin states. Figure 1 incorporates the higher water use rates projected by Glenn and relates the supply available to Colorado with varying assumed levels of flow in the Colorado River. Using the optimistic estimate of 14.1-14.8 maf, which would provide in excess of 5.8 maf to the upper basin states, Colorado will approach a deficit position between 1990 and 2000. Colorado's share of the 5.8 maf equals 2.976 maf which, if Glenn's projections are adopted, will be exhausted shortly after 1990. A more conservative estimate, in the range of 13.3 maf, yielding 5.0 maf to the upper basin states reduces Colorado's share to 2.59 maf, a situation which indicates a deficit supply prior to 1990. Utah (Figure 2) is in much the same position as is Colorado. If river flow is sufficient to provide 5.8 maf to the upper basin states, and if Utah's share of this allocation is 1.4 maf, that state should have a supply sufficient to meet projected use through the year 2000. However, the more conservative estimate of 13.3 maf, and an upper basin share of 5.0 maf, indicates that Utah's share of 1.15 maf will be sufficient to meet projected needs only slightly beyond 1985.

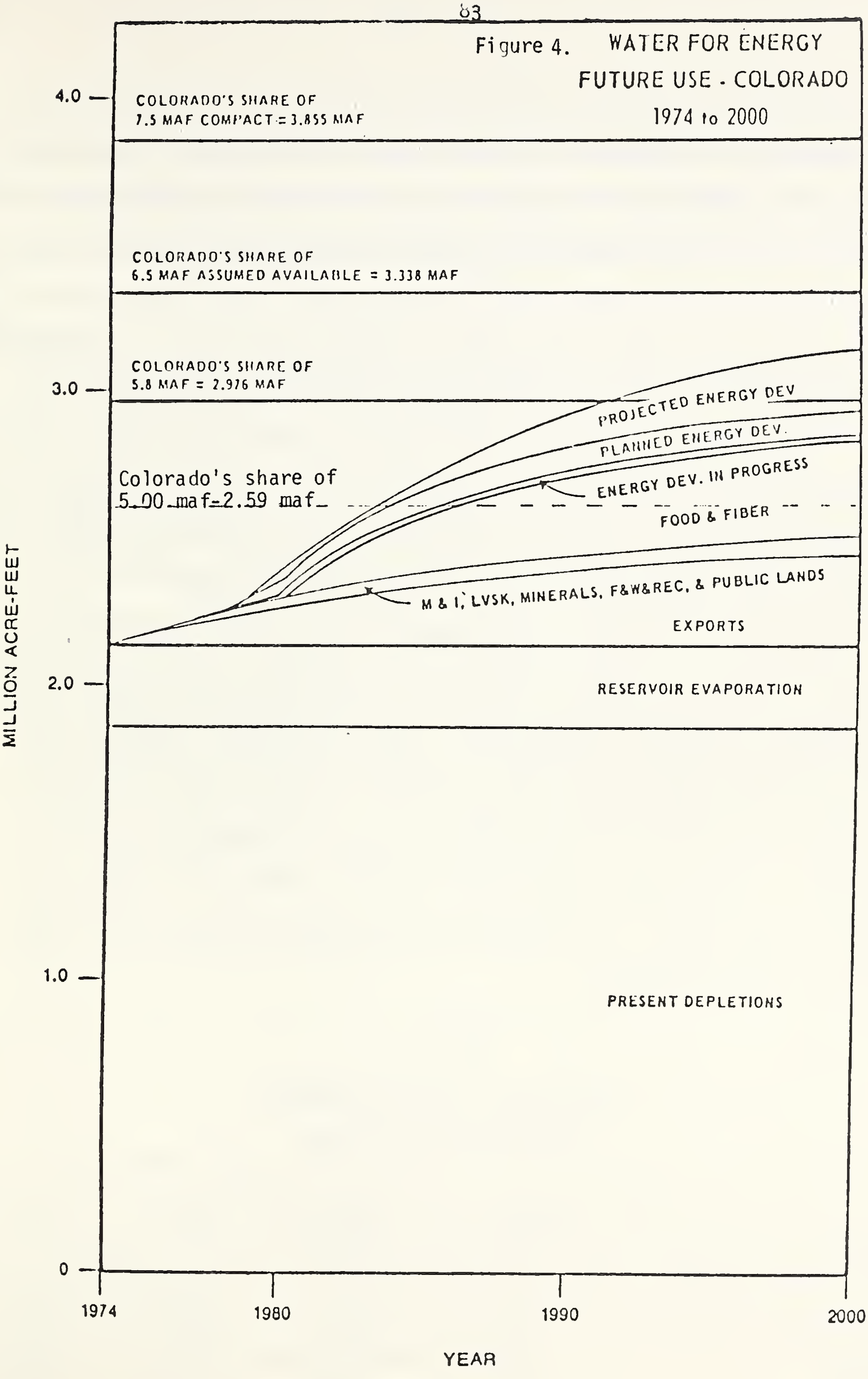
Of the upper basin states, only Wyoming seems assured of a water supply sufficient to meet projected water use rates through the year 2000, even under the conservative estimates of water supply.

The foregoing description of water supply, current water use rates, and projected use rates makes it rather apparent that a definitive statement of water available for future energy development is unlikely. Obviously, projected, if not present, water deficits in the lower basin states will quickly be realized. Equally obvious is the fact that there is insufficient water to meet

FIGURE 3. WATER FOR ENERGY
FUTURE USE - UTAH
1974 to 2000



Source: USDI, 1974.



Source: USDI, 1974

all planned uses in Colorado and Utah through 2000 and 2020. Of the upper basin states, only Wyoming appears to be secure in this regard. On the other hand, even the restrictive assumption of Colorado River flow of 13.3 maf leaves a current surplus surface water supply for coal and oil shale (and other uses) in the upper basin states. While there are more planned uses for this water in Colorado and Utah than can be supported, a sizable coal and oil shale sector could be developed without necessarily detracting from current uses. Competition among uses is, however, quite likely in the not-too-distant future, and if energy development requires diverting water from planned agricultural and municipal uses, some reordering of priorities will be needed.

The importance of ground water mining as a means of financing surface water deficits has been mentioned particularly for the lower basin states. The Sevier Lake Subregion provides a good example. Table 9 presents a summary of the current and projected use of water in relation to surface water supplies. It is evident from Table 9 that the present level of consumptive use is in excess of surface water supplies and that this deficit is projected to increase through 2020. It is apparent that ground water mining will be increasing in this subregion.

TABLE 9

SEVIER LAKE SUBREGION SUMMARY

(1000 ACRE-FEET PER YEAR)

	Present	1980	2000	2020
Surface Water Supplies	912	912	912	912
Depletions	962	968	1008	1057
Residual	- 50	- 56	- 96	- 145

Since projections for the North Platte River Subregion are unavailable, consideration is confined to the present relation of depletions to supplies. With present depletions of 132,000 acre-feet per year and a supply of 600,000 acre-feet, an excess annual supply of 468,000 acre-feet exists in this subregion.

Groundwater

The available data on water supplies, current use and projected water requirements indicate that one, or a combination, of several courses of action must be taken in regard to future water use in the Rocky Mountain States. The possibilities include, but are not necessarily limited to: (1) development of water-saving technology in existing uses; (2) transfer of water rights from low valued to high valued uses; (3) transfers of water between basins; and (4) development of additional supplies from ground water sources. It is to this latter possibility that discussion is directed in this section of the report.

Use of ground water has both advantages and disadvantages when compared to utilization of surface water. On the negative side, ground water can be depleted. In this sense, under certain circumstances, it is a stock or nonrenewable resource. The critical factor here is the net recharge rate of the particular aquifer, where the recharge rate is the quantity of water, per unit of time, that enters the aquifer from alternative sources. When the recharged rate is less than the rate of withdrawal, i.e., the net recharge is negative, this resource is being mined. However, given favorable recharge conditions, utilization of ground water does have an important advantage over surface water in that a well can be drilled at almost any location over the aquifer and will yield a dependable quantity and quality of water. Spatial limitations, extreme seasonal fluctuations in supply and associated variations in quality may be much more prevalent in the use of surface water.

However, the certainty of supply suggested above may not be the case. The hidden or invisible nature of ground water creates a handicap and requires extensive hydrologic and geologic study to assess the quantities of water available. In the absence of such studies, reliance on increased ground water use as a source of supply is a tenuous business. Uncertainty of supply is characteristic of this case and overdevelopment, resulting in excessive pumping costs and dry wells, may occur. Further problems may be caused due to the interrelationship between surface and ground water supplies. As ground water supplies are depleted, surface water drawdown increases, as may drawdown in other aquifers.

Ground water supplies generally have no direct habitat value and if surface-groundwater interrelationships are minor, ground water can be developed exclusive of concern for losses of wildlife and aquatic ecosystems. However, if the interrelationship is substantial, indirect habitat values may be quite important. This interrelationship is variable, depending upon the hydrologic and geologic conditions of the aquifer and proximate areas. These considerations are suggestive of the need for extensive study prior to ground water development.

Finally, disruption by stripmining and land subsidence are other disadvantages associated with ground water development.

Appraising the ground water supplies available for future development for use in energy or other alternatives is difficult. However, it is generally concluded that, in the Rocky Mountain region, additional development of ground water will result in mining. Estimates of ground water availability in the region are not plentiful, and are particularly scarce for deep aquifers. The following discussion presents data available on ground water supplies for the subbasins identified previously.

Table 10 lists the estimated amounts of ground water stored in the upper 100 feet of underlying aquifers in the Upper and Lower Colorado Regions and the

Sevier Lake Subregion. Realistically, these figures serve as upper bounds on the amount of ground water available for use.

TABLE 10

ESTIMATED STORAGE OF RECOVERABLE GROUND WATER

IN UPPER 100 FEET OF AQUIFER SATURATED THICKNESS

(1000 ACRE-FEET)

Upper Colorado	82,940,000
Lower Colorado	473,000,000
Sevier Lake Subregion	21,700,000
TOTAL	577,640,000

SOURCES: Upper Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, p. 21.

Lower Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, p. 18.

Great Basin Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, p. 48.

The ground water supplies indicated in Table 10 are dispersed across large areas and therefore their recovery and use may not be economical at the present time. Unfortunately, it is not feasible to calculate the amount of ground water which can be economically recovered because variables such as location, availability and cost of surface water, type of use, and the costs of obtaining ground water must be specifically considered.

Upper Colorado River Basin

At present ground water within the Upper Colorado River Basin is relatively undeveloped. In 1970, ground water use amounted to only 2 percent of this

region's total withdrawals and depletions.[72/] Of the 63,000 acre-feet of depletions from ground water supplies, irrigation accounted for 52 percent; public supplies, 25 percent; domestic and livestock, 17 percent; and industry, 6 percent.[73/]

Recharge to aquifers in the Upper Colorado River Basin is estimated to be capable of supporting four million acre-feet of groundwater pumpage per year without reducing ground water levels.[74/]

Lower Colorado River Basin

In sharp contrast to the Upper Colorado Basin, ground water accounts for a large proportion of total withdrawals in the Lower Colorado Basin. Regionally, ground water withdrawals constitute 61 percent of total withdrawals.[75/] Table 11 shows that the Gila Subregion is primarily responsible for this large ground water use.

TABLE 11

WATER WITHDRAWALS OF THE LOWER COLORADO RIVER BASIN

(1000 ACRE-FEET PER YEAR)

Subregion	Groundwater	Surface Water	Total Withdrawals
Lower Colorado	525	1,896	2,420
Little Colorado	74	78	152
Gila	4,465	1,231	5,696
TOTAL	5,064	3,204	8,268

Source: Lower Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, June 1971, p. 31.

In the Gila Subregion 78 percent of water withdrawals is obtained from underground. Ground water mining has been extensive in this subregion and has resulted in rapidly falling ground water levels. In one valley the ground water

level declined an average of 13.8 feet per year from 1958 to 1967.[76] In some smaller areas the situation has been worse.

For the 1970 level of development an estimated 2.2 million acre-feet of ground water was mined in the State of Arizona.[77] Mined ground water for the Lower Colorado River Basin was estimated to be 2.5 million acre-feet during 1965.[78] This is about one-half of the total ground water withdrawals shown in Table 9.

Sevier Lake Subregion

Natural discharges, such as springs, total 328,000 acre-feet per year in the Sevier Lake Subregion, with 106,000 acre-feet being consumed at the 1965 level of development.[79] This leaves 222,000 acre-feet for increased future use. However, points of discharge are dispersed and thus full development of available ground water is rendered difficult.

Ground water withdrawal from wells amounts to 280,000 acre-feet per year in the Sevier Lake Subregion, which includes 17,000 acre-feet mined.[80]

Some final notes are in order concerning the capability of ground water supplies to aid in the provision of water supplies for the development of energy resources. The ground water supplies discussed above lack the capability to support major localized development for extended periods. Therefore, although these ground water resources may provide water for short-term alternative uses such as irrigation, they cannot be the sole source of supplies for conversion facilities. Ground water from deep aquifers may be better suited to directly supply water for energy development but data limitations prohibit an evaluation of the potential of these aquifers. Finally, because of surface-groundwater interrelationships, hydrologic studies should be performed to determine the localized impact of specific energy facilities.

CHAPTER IV FOOTNOTES

62/ This portion of the report draws heavily from Gray, S.L., et. al., "Water Resource Base in the Rocky Mountain Region" report submitted to NRED, ESCS, USDA, 1977, and Whittlesey, N.K., and Cooperative Service, USDA, Natural Resource Economics Division, Working Paper No. 46, 1978.

63/ USDI, Report on Water for Energy in the Upper Colorado River Basin. Water for Energy Management Team. July, 1974.

64/ USBR, Quality of Water, 1975, Colorado River Basin, Progress Report #7: Washington, D.C., 1975.

65/ Andrews, Chas., et. al., Oil Shale Development in Northwestern Colorado: Water and Related Land Impacts. Water Resource Management Workshop, Institute for Environmental Studies, Report #48. University of Wisconsin, July, 1975.

66/ Gardner, B. Delworth, et. al., The Effects on Agriculture in Utah of Water Transfers to Oil Shale Development. PRJAE-027-1, Utah Water Research Lab, USU, Logan, Utah. June 1976.

67/ Sparks, Felix L., Water Prospects for the Emerging Oil Shale Industry. Presentation to 7th Oil Shale Symposium, Colorado School of Mines, April 1974.

68/ Glenn, Bruce P., Water Availability to Meet Future Competing Demands . . . Paper given at Western Resources Conference, Fort Collins, Colorado. July 1976.

69/ Lower Colorado Region Comprehensive Framework Study, 1971.

70/ Witness Arizona, which is currently, and heavily, mining available ground water supplies.

71/ Glenn, op. cit., 1976.

72/ Summary Appraisals of the Nation's Ground-Water Resources--Upper Colorado Region, Don Price and Ted Arrow, U.S. Geological Survey Professional Paper 813-C, 1914, p. C17.

73/ Ibid.

74/ Ibid., p. C1.

75/ Lower Colorado Region Comprehensive Framework Study, Pacific Southwest Inter-Agency Committee, Water Resources Council, June 1971, Appendix V, Water Resources, p. 31.

76/ Arizona State Water Plan - Phase I, Summary, Arizona Water Commission, July, 1975, p. 12.

77/ Ibid., p. 9.

78/ Lower Colorado Region Comprehensive Framework Study, p. 31.

79/ Great Basin Region Comprehensive Framework Study, Pacific Southwest Inter-Agency Committee, Water Resources Council, June 1971, Appendix V, Water Resources, pp. 56,57.

80/ Ibid., pp. 51, 52.

CHAPTER V

Introduction

Chapters III and IV discussed water resources of the Northern Great Plains and the Rocky Mountain Regions along with projections of use to the year 2000. In this chapter we focus more specifically on the future use of water in energy development relative to regional water resources. Projections of water consumption by energy development and other sectors make it clear that there will be competition between various users in the near future at least in the State of Colorado. If this competition were to be mediated through a well developed market for water rights, the predictable result would be a rise in the real price of water. But Chapters I and II plainly illustrate that the market is subject to numerous institutional restraints. Furthermore, there are physical barriers to reallocation of water even within the boundaries of a given state.

The obstacles on the supply side tend to fragment markets for water rights. This tendency to market fragmentation will be reinforced on the demand side by the point specific water needs of energy processing. The net result should be very uneven upward pressure on water value across sub-basins. Accordingly, this chapter tries to identify those sub-basins which may feel the greatest pressure on water values. Because the pressure may be extreme in some places, it is worthwhile to determine the scope of water users (both agriculture and energy processing) to switch to water-efficient technologies.

Estimates of Water Requirements for Alternative Coal and Oil Shale Processing Technologies

Coal and oil shale technologies which are given some chance of adoption in Western States energy development are discussed below along with estimates of their rates of consumptive water use. Technologies for coal exploitation are

relatively better developed than those for oil shale, none of which has yet been applied on a commercial scale. Consequently, consumptive water use estimates for most coal technologies are subject to less uncertainty: their discussion is taken first.

Coal mining and washing may account for significant water consumption depending on whether mining is open pit or underground. Underground mining often requires that coal be washed before use, while open pit mining typically does not. Water use in the Kaiparowits mines for washing and mining is reported to be about 164 acre feet per one million tons mined. This translates into 1821 acre feet annually for the coal to feed a 3000 Mwe generating plant.[81/] For comparison, coal strip mined at Gillette, Wyoming and fed to a similar generating plant is expected to use only 235 acre feet of water per year for mining.[82/]

Transportation of coal will consume significant amounts of water only if pipe line slurry is used. EPA uses a figure of 18,421 acre feet of water to operate a 25 million ton per year slurry; enough coal to operate roughly 7000 megawatts of electrical generating capacity for one year.[83/]

Electricity generation requires large quantities of water, and is the least water efficient method of coal processing: 43 to 54 gallons per one million Btus of coal energy delivered versus 14 for a slurry pipeline. This method of coal processing is in widespread commercial use. Estimates of annual consumptive water use for mine mouth, 3000 Mwe plants vary from 24,000 acre feet for the proposed Kaiparowits plant to 22,000 acre feet in Wyoming and Montana (includes mining use of water). These estimates are based on wet tower cooling. Dry tower cooling could cut this by 90%, but the cost of water would need to be at least four times present costs to justify dry tower cooling over wet tower cooling (except in Gillette, Wyoming, where the break even point

is 62% above the current cost of water delivered to the plant. [84/]

Coal Gasification is given a fair chance of commercial operation in the Powder River Basin and the Fort Union Region. From 9 to 11 million tons of coal are needed annually to run a Lurgi process coal gasification plant providing 250 million cu. ft. of gas per day. An alternative process, Synthane, uses from 8 to 10 million tons of coal for the same output. The Lurgi process would be expected to consume from 3,307 to 5,639 acre feet of water per year while the comparable Synthane process is estimated to consume 7,671 to 8,670 acre feet per year. It is worth noting that these EPA estimates are significantly lower than earlier estimates; for example a 1974 estimate of the annual water consumption of a 250 million cu. ft. per day Lurgi process was 20,000 acre feet. [85/]

Synthetic Oil may be produced from coal; the process is estimated to consume between 9 and 12 thousand acre feet of water annually to produce 100,000 barrels of oil per day. The coal used would be 80% to 95% greater than that used by 250 million cu. ft. per day gasification plants.[86/] Water consumption per million Btus is generally lower (15 to 19 gallons) for synthetic oil than Lurgi (14 to 24 gallons) or synthane gas (32 to 36 gallons).[87/]

Apparently, there is a spectrum of alternatives for coal processing which varies in water use from negligible to very heavy. While it appears that mine mouth electricity generation will employ wet tower cooling, it is possible that high water costs may make transportation via unit trains or pipeline slurry more attractive than mine mouth processing. Still, dry tower cooling is an alternative which would permit mine mouth processing. In terms of 1973 costs, however, unit trains still held an edge over extra high voltage power lines in transporting some western coal energy distances over 1000 miles.[88/] High water costs at the mine mouth combined with increasing resistance to extra high voltage power lines may be enough to tip the scales in favor of export.

In summarizing, it is instructive to compare the efficiency of water use by the various alternatives in coal processing:

Table 1

WATER CONSUMPTION IN COAL PROCESSING ALTERNATIVES

Process	Net water consumed per million Btus
Lurgi	14-24 gallons
Synthane	32-36 gallons
Synthoil	15-19 gallons
Slurry Pipeline	14
Electric Generation	43-54*

*gallons/million Btus of Heating value of input coal (Source: EPA 1977, p.7)

Oil Shale Processing

An important difference between oil shale processing and coal processing is the much greater throughput of shale material per Btu output. Transportation is therefore ruled out for oil shale and processing will be either mine mouth or in situ (literally in the ground). No large scale oil shale processing facility is yet under construction, let alone operational, so that estimates of water usage vary widely. EPA estimates are based on a mine mouth process, TOSCO-II, which involves crushing the shale and then heating (retorting) it to produce the oil. After retorting, the shale oil is too thick to be piped and too high in sulphur and nitrogen to be fed to a standard refinery. Therefore, it must be upgraded through a refinery process which consumes water. Additionally, spent shale from the retort must be compacted for disposal, again consuming water. EPA estimated that a 100,000 barrel per day shale oil refinery would consume a total of nearly 13 thousand acre feet of water per year.[91/] Of this water, 1,768 acre feet are used in the refinery and 3,629 acre feet are used in spent oil shale disposal. There are indications that oil shale can be processed without crushing to a very small size, eliminating

the need for water in spent shale disposal. Water requirements could also be lowered by transporting the thick crude oil via a heated pipe or an insulated tank car to another area. If these two alternatives were chosen, consumptive water use could be reduced by 41% to 7,527 acre feet per year for a 100,000 barrel per day operation.

Current advances of in-situ retorting processes may result in further reduction in water consumption by oil shale production. For example, a recent estimate of water consumption for a commercial plant is provided by Ashland Oil's updated Detailed Development Plans for the C-b tract in the Piceance Creek Basin of Colorado. Using a modified in-situ mining technique, this 57,000 barrel per day process would require a water supply of 2,500 gpm.[89/] This equals about 11 acre feet per day or 4,036 acre feet per year. The estimated mined water available during full operation is expected to be about 2,000 gpm. From this calculation it may be seen that water needs during the plant commercial operation phase are to be approximately 2,500 gpm of which nearly 2,000 gpm would be provided by the mining activity itself leaving a net import of about 500 acre feet per year. These estimates of water consumption for the modified in-situ process include uses for all plant activities plus steam generation for retorting, for heating and processing requirements, drinking water, evaporation losses and use of irrigation water in revegetation. Off site water requirements for ancillary activities are not included in this estimate.

The Rio Blanco oil shale project for the C-a tract of the Piceance Basin estimated that after full development of 55,800 barrels per day there would be an annual consumption of water of 10,000 acre feet.[90/] Of this total 41 percent is allocated for use on processed shale disposal, 30 percent for retort and vent gas losses, 25 percent for cooling water losses, the remaining

5 percent being chemically converted or lost in miscellaneous manner. The RBSP Rio Blanco Oil Shale Project also indicated that the raw water intake of about 8,300 acre feet per year would be provided from ground water once the development reaches full scale operations. Additionally 450 acre feet per year would be water produced in the retort process. Thus, it is not expected that development of the C-a tract through open pit mining would require an outside water supply.

Finally, there is strong evidence that ground water may play a key role in the exploitation of the largest oil shale deposit; the Piceance Creek Basin. Recent work in the area indicates that most of the water requirements for processing can be satisfied by de-watering of the mine zone. If this is the case, then it is possible that earlier estimates of water consumption by oil shale processing were inflated in order to assure sufficient water once development is under way.

Table 2 summarizes the range of estimates of consumptive water use by oil shale processes. Amounts given are per 1,000 barrel day capacity.

Location of Energy Development

In this section projected energy developments are examined relative to the location of water resources. Choice of location of processing facilities can affect water costs both through delivery and through competition with alternative uses. To the extent that these costs are a significant part of the total cost of energy conversion, the spatial pattern of energy development will be influenced by water consideration.

Patterns of Energy Development in the Rocky Mountain Region

Location of processing plants in the Rocky Mountain States is easier to predict than in the Northern Great Plains. First of all, the greatest part of

Table 2 Water Consumption per 1000 barrels per day of shale oil produced -- acre feet per year.

Process Requirements	Underground Mine (Room & Pillar)a/	Surface Mine (open pit) a/	In Situ a/	Modified In Situ b/	Mod. In Situ w/processing of void shale c/
Mining and crushing	7-10	7-10		2- 3	1- 2
Retorting	12-15	12-15		3- 4	5- 7
Shale Oil Upgrading	29-44	29-44	29-44	19-29	19-29
Processed Shale Disposal	58-88	58-88		17-27	25-35
Power Requirements	15-20	15-20	15-36	10-22	9-18
Revegetation	0-14	0- 7	0-14	0- 9	0- 7
Sanitary Use	0- 1	1- 2	0- 1	0- 1	0- 1
Sub Total	121-192	122-184	44-96	46-96	59-99
Associated Urban					
Domestic Use	13-18	11-15	14-17	14-17	11-15
Domestic Power	1- 2	2- 3	1- 2	1- 2	1- 2
Sub Total	14-20	13-18	15-19	15-19	12-17
Total	135-210	135-202	59-115	61-115	71-116
Average	174	168	88	88	94

a/ Adopted from USDI, 1974

b/ Estimated distribution from USDI, 1974 and quantity from Ashland, Inc., 1977.

c/ Estimated as a combination of other methods.

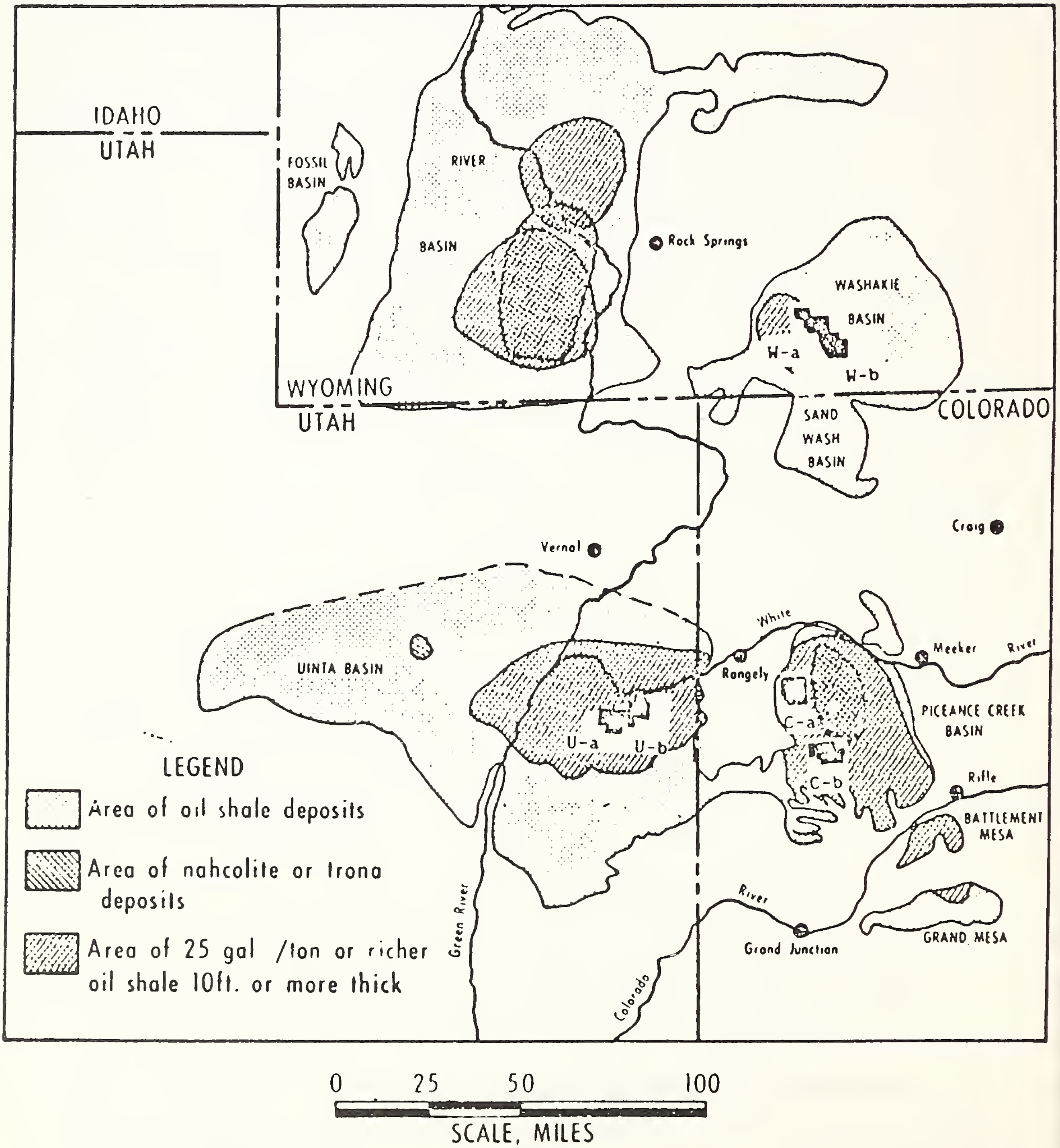
projected energy processing is oil shale which is quite localized in the Green River and White River Basins of Colorado, Utah, and Wyoming. Secondly, most of the coal mined in the region is expected to be exported. For this reason, the coal processing demand for water in the Rocky Mountain region is not considered in this report. Rather, attention is focused on the potential water demand of oil shale processing.

The Green River oil shale formation shown in Figure (1) contains close to 60% of the known U.S. oil shale deposits of greater than 25 gallons of oil per ton of oil shale. The richest of these deposits lie in the Piceance Creek Basin near the White River, and it is here that most experimental development has taken place to date. It is expected that this area will also see the first commercial development; three scenarios used by the EPA all show this region producing 200,000 barrels per day by 1985 and over 3 million barrels per day by the year 2000.[92/] See Table 3 for EPA's assumed distribution between states.

Although it is probably correct to assume initial development in the Piceance Creek area, there is reason to expect that Colorado's oil shale development may be hampered by institutional restraints. As was seen in Chapter IV, uncommitted water potentially available for oil shale development in Colorado is on the order of 90,000 acre feet per year. If oil shale development consumes as much water as the EPA estimates (12,924 acre feet annually per 100,000 bbl day capacity), and if all requirements are met from surface water, then the projected 1990 development (about 700,000 bpd) would not push water use above the 90,000 acre foot limit. But development of a 3 million bbl per day industry would require over 400,000 acre feet per year. If this were all met from surface water it would nearly equal the 451,000 acre feet available to Utah, Wyoming, and Colorado combined. Moreover, that availability is predicted on a gross flow of 14.1 million acre feet of water at Lee Ferry. If a more conservative 13.3 million acre foot figure is

Figure 1

OIL SHALE AREAS
COLORADO, UTAH, AND WYOMING



used, Colorado's 90,000 acre feet would disappear as would over 200,000 acre feet of other, already committed uses (see Table 2, Chapter IV).

Extensive oil shale development in the Piceance Basin will clearly result in competition between energy and other users of water. If the market is allowed to function, it is also clear that the additional water will be supplied by agricultural users: Irrigation water value is about $20 per acre foot while a $200 per acre foot cost to the oil shale industry would account for only $.07 per barrel of oil. It should, however, be remembered that Colorado water law allows the sale of only that proportion of agricultural water historically consumed and only during the historical periods of irrigation. This implies added costs through shrinkage of water rights and through costs of storage and transportation facilities necessary to assure a steady flow at mine sites. Nevertheless, even under an assumed 13.3 million acre foot flow at Lee Ferry, the total Colorado share of the Colorado River flow is 2.59 million acre feet, of which at least half is used for irrigation.

Utah has less attractive oil shale deposits than Colorado, but a political posture much more favorable toward oil shale development. For example, the state of Utah plans to build a dam on the White River to supply water to the oil shale industry. Recognizing such political/legal factors, table 4 presents an alternative to the EPA projections presented in table 3. This alternative is shown as a means of comparing the water needs of each state with anticipated water availability. Reference to table 3 of Chapter IV shows, for each of the oil shale states, the water available for oil shale development without reallocation, both for higher and for lower quantities of water. Table 5 provides a summary of the findings of chapter IV as well as a comparison of potential water supplies and demands for oil shale development.

Table 3 - Oil Shale Development and Water Use in Rocky Mountains Region by 2000--EPA Scenario

	Low Demand	Nominal Demand	Low Nuclear Availability
Colorado	3.2 million barrels per day / 413,568 Acre ft. water per year	3.8 million barrels per day / 491,112 Acre ft. water per year	3.7 million barrels per day / 478,188 Acre ft. water per year
Utah	.3 million barrels per day / 38,772 Acre ft. water per year	.4 million barrels per day / 51,696 Acre ft. water per year	.4 million barrels per day / 51,696 Acre ft. water per year
Wyoming	————	————	————

Source: EPA, 1977, pp. 221-244.

Table 4 - Water Requirements for Oil Shale Production, by State--Whittlesey's Scenario

	unit	Colorado	Utah	Wyoming	Total
250,000 bpd					
Distribution	percent	65	35	--	100
Water demand	1000 AF	17.41	9.37	--	26.78
500,000 bpd					
Distribution	percent	63	37	--	100
Water demand	1000 AF	36.32	21.43	--	57.65
1,000,000 bpd					
Distribution	percent	66	28	6	100
Water demand	1000 AF	78.41	33.26	7.13	118.80
2,000,000 bpd					
Distribution	percent	67	28	5	100
Water demand	1000 AF	151.27	63.22	11.29	225.78

Source: Whittlesey, 1977b, Table 42.

Table 5--Comparison of potential water supplies and oil shale water demands.

	Colorado	Utah	Wyoming	Total
		---- 1000 AF ----		
Water supplies for oil shale				
Higher case a/	90 c/	128	233	451
Lower case b/	0	111	223	334
Water demand				
250,000 bpd	17	9	0	26
500,000 bpd	36	21	0	57
1,000,000 bpd	78	33	7	118
2,000,000 bpd	151	63	11	225

a/ Based on assumed flows in the Colorado River of 14.0 million acre feet.

b/ Based on assumed flows in the Colorado River of 13.3 million acre feet.

c/ The amount that could be used for oil shale is 154,000 AF if 64,000 AF of over commitment to other uses is withdrawn and made available to oil shale.

Source: Whittlesey, 1977b, table 43.

Assuming that the lower water supply case occurs, what is the probable effect of large scale energy development on agriculture? Meeting the water demands of oil shale development in Utah and Wyoming should not detract water from agricultural uses. In fact, Utah's planned dam on the White River would allow development of about 13,000 acres of irrigated Ute Indian land near the confluence of the Green and White Rivers. Thus, oil shale development in Utah may increase agricultural output, at least in the short run.

Colorado presents a different set of circumstances: under the lower level of Colorado River flow an oil shale industry in the very infant stages of development would begin to compete with agriculture for water. Assuming the water demand/supply data of Table 5 are accurate and that all such water must be provided by surface flows in Colorado, it is possible to estimate how seriously oil shale would impact on agriculture.

Table 6 shows the current agricultural base in the major drainage basins of Colorado which could provide surface water for oil shale development. There are currently about 413,000 acres of irrigated land in these two basins consuming about 770,000 acre feet of water per year. Assume the worst possible case to prevail in which all of the water for a 2,000,000 bpd industry would come from agriculture, that is, 151,000 acre feet. At the average rate of water depletion of 1.86 acre feet per acre of land this could reduce irrigated acreage by 81,000 acres. This would mean a potential reduction of 20 percent in the irrigated agriculture of these two basins in order to support oil shale development.

How probable is this worst possible or lowest case? There are a number of factors to be considered that would certainly qualify the potential detrimental impacts on agriculture.

Table 6 -- Agricultural water use in major oil shale regions of Colorado.

Crop	Unit	Colorado River Mainstem a/	Northwest Region b/	Total
Wheat	1,000 ac	1.6	1.2	2.8
Corn grain	1,000 ac	7.5		7.5
Corn silage	1,000 ac	5.2		5.2
Oats	1,000 ac	1.6	0.5	2.1
Barley	1,000 ac	3.5	1.0	4.5
Orchard	1,000 ac	4.3		4.3
Vegetable	1,000 ac	0.7		0.7
Alfalfa hay	1,000 ac	62.7	22.3	85.0
Other hay	1,000 ac	57.1	106.8	163.9
Dry beans	1,000 ac	0.3		0.3
Crop pasture	1,000 ac	39.1	32.5	71.6
Other pasture	1,000 ac	36.2	28.8	65.0
Total acres		219.8	193.1	412.9
Total water depletion	1,000 ac	444.8	324.6	769.4
Average water depletion per ac	AF	2.02	1.68	1.86

Source: Whittlesey, 1977a.

a/ Includes Eagle, Garfield, Grand, Mesa, Pitkin and Summit Counties.

b/ Includes Jackson, Moffat, Rio Blanco and Routt Counties.

It has been illustrated above that there are definite technological options in mining, retorting, and upgrading oil shale that could adjust the water use in the industry over a wide range. Thus, the water coefficients used in this report and elsewhere are generally considered to be a "worst case" condition. If water is available and cheap the oil shale industry will probably use it in significant quantities. If water supplies become restrictive the industry can probably develop using much less water than previously anticipated.

It should also be recognized that some of the conditional claims on Colorado water rights are held by industries whose intent is to use this water for oil shale development. Also, Colorado's water commitments include as much as 90,000 acre feet of water in Green Mountain Reservoir and Reudi Reservoir which could be made available to the oil shale industry. Further, we cannot ignore the potential contribution of groundwater to the oil shale industry. It is believed that several million acre feet of groundwater may eventually be available in the Piceance Basin.

There is some indication that there may be opportunities for "saving" enough water in agriculture to offset the needs of an oil shale industry. Table 7 illustrates the opportunities for achieving this reduction in water use in agriculture. Of course, the costs could be very high for achieving significant gains in water use efficiency and there would have to be changes in the legal and institutional factors surrounding water rights in order to compensate agriculture for such costs and to divert the saved water to energy development.

On the other side, the local effects on agriculture may be harsh. An underlying assumption of this analysis is that no intrabasin water distributional problems will occur. On the contrary, some of the "available" water

Table 7. Water depletion by agriculture under alternative conditions of efficiency - Colorado

	Present Condition	Improved Management	Lined Canals	New Technology[a/]
	- - - - - - - - -	-1,000 acre feet-	- - - - - - - - -	
Colorado River Mainstem	445	428	415	366
Northwest Region	325	311	315	279
Total	770	739	730	645
Reduction from present	-	31	40	125

[a/] The new technology condition includes lined canals, improved management, and new on-farm irrigation systems.

Source: Whittlesey, 1977a.

within state (particularly Colorado) is in river subbasins away from the oil shale area per se; the localized nature of the oil shale water demand will negate much of the potential "saving" possible in agriculture. If, for example, most of the Colorado oil shale water were drawn from one subbasin, on-farm investments reflected in column 4 of Table V-7 would be unprofitable because the subbasin's farmers and ranchers must compete with farmers in neighboring subbasins which retain plentiful agricultural water supplies. Consequently, the local or regional impact of large diversions of surface water to oil shale development could vary from positive for neighboring subbasins to critical for the directly affected subbasin.

Patterns of Coal Development in the Northern Great Plains

In contrast with the oil shale deposits in the Rocky Mountain region, coal deposits in the Northern Great Plains are widely dispersed. Proposed sites of Northern Great Plains coal processing plants are close to mine sites which are in one of two regions--the Fort Union and the Powder River Regions (see figure 2). The Fort Union region lies in eastern Montana and in the

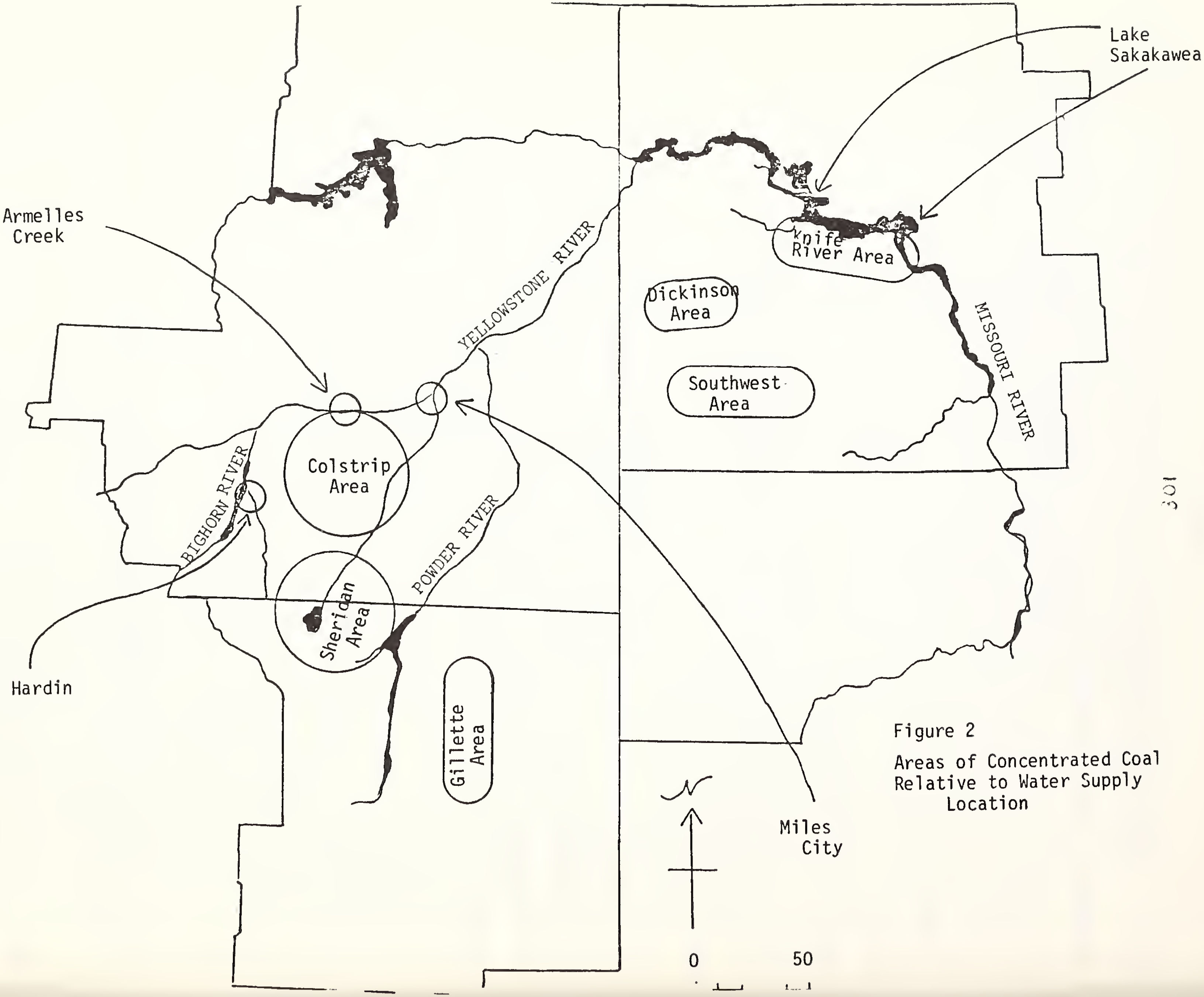


Figure 2

Areas of Concentrated Coal Relative to Water Supply Location

western Dakotas. The Powder River region is in southern Montana and northern Wyoming, and has thick deposits of sub-bituminous coal which is of generally higher energy content than the lignite deposits of the Fort Union region.

For the purpose of relating coal exploitation to regional water, six subregions are identified in which coal exploitation is likely to be concentrated. Three of these subregions are in the Powder River region and three in the Fort Union region. Some developments will take place outside of these six subregions, but they are likely to be much less concentrated.

Beginning in the southern Powder River region, there is intense interest and current mining near Gillette, Wyoming. The exploitable deposits in this area run north and south of Gillette, and just outside of the Powder River Basin (see Figure 2). Another area of interest already being exploited lies between Sarpy Creek and Armelles Creek, which flow north directly into the Yellowstone River between Billings and Miles City. We will label this the Colstrip area (see Figure 2). Between the Colstrip area and the Gillette area are a number of existing and potential mine sites, most of which lie in the Tongue River Basin. These comprise the third area which we label the Sheridan area.

Projected coal developments in the Fort Union region are mostly in the southwestern corner of North Dakota. This area is subdivided into three subregions. The Knife River area is the area immediately south of Lake Sakakawea. A second subregion is in Billings and Stark counties northwest of Dickinson, North Dakota, and is labeled the Dickinson area. Finally several sites are located in the far southwest corner of North Dakota, and this is labeled the Southwest area.

The significance of location of processing sites becomes apparent when the quantity and location of water supplies are re-examined. Proven <u>groundwater</u> supplies are generally modest, already in use, and connected with surface

water flows.[93/] There is evidence that a large and very deep aquifer known as the Madison Group underlies parts of the coal areas in Montana and Wyoming. The extreme depth of this aquifer and its unknown capacity make it a questionable source of water for coal development. Consequently, attention is concentrated on the supply of surface water.

Surface water volume physically available in the Yellowstone-Missouri River System above Garrison Dam is subject to some uncertainty because of unreliable records of depletions prior to 1910. However, records of increases in average annual depletions since 1910 are considered reliable and these, along with measured annual flows give a rough upper bound on physical availability of surface water at various points in the river systems. Table 8 shows the critical year minimum annual flow at various points in the system, and for comparison, the total of industrial water options and applications for options are shown by river.

It is assumed that minimum flow is the same as "unused" water, although this is plainly not the case, since water is required to maintain wildlife populations, aesthetic enjoyment, etc. Nevertheless current water use is heavily dominated by irrigation, and if industrial uses are allowed to compete on the market with agricultural uses, irrigation water rights will be sold. Still it is not clear that it will be necessary to withdraw water from irrigation even with fairly extensive coal development in the Yellowstone Basin.

Table 8 shows that surface water on the mainstem Missouri River is far in excess of anticipated industrial demand. Furthermore, large dams exist on the Missouri including the Fort Peck Dam at Northern Montana and the Garrison Reservoir in North Dakota. Water from the Garrison Reservoir (Lake Sakakawea) could be used for coal development in North Dakota since tributary flows in that area are light and irregular. On the other hand, Yellowstone water is

Table 8

Regional Water Supplies and Potential Demand

River and location	Critical Year Flow (Acre-Feet)	Industrial Water Options Contracted or Applied for as of October, 1974
Yellowstone Basin:		
Clarks Fork Yellowstone	538,000	
Wind-Bighorn near mouth	1,429,000	1,219,000
Tongue near mouth at Miles City, MT	48,800	4,000
Powder at Moorehead, MT	98,600	220,000[b]
Yellowstone near Sidney	4,797,000	1,543,000
Upper Missouri Basin:		
Missouri near North Dakota border	7,276,000[a]	732,000[c]
Western Dakota Tributaries:		
Little Missouri near mouth	62,000	36,000
Knife near mouth	19,800	
Heart near mouth	17,000	18,000
Cannonball near mouth	1,000	
Grand near mouth	9,000	19,000
Upper Missouri Basin:		
Missouri River at Lake Sakakawea	16,952,00[a]	460,000[a]

(a) Average annual flows.
(b) From Moorhead Reservoir (potential).
(c) From Fort Peck Reservoir.
(d) From Oahe Reservoir and Lake Sakakawea

Sources: 1. NGPRP Water Work Group Report, pages 13-21.
2. Table III-3 of this report.

less abundant, and, while anticipated requests for Yellowstone water could, in principle, be met, there is not sufficient storage in the Yellowstone River System to assure year-round consistent flows to processing plants with extensive coal development. The NGPRP water work group calculated instream requirements for most streams in the Yellowstone Basin which may be affected by withdrawals for coal development. Their calculations allow for minimum stream flows which will sustain the current aquatic environment of the river systems. Table 9, column 1, shows water available at five points in the Yellowstone Basin under the assumption that all current uses and instream requirements are met. Left hand figures in column 1 of Table 9 assume only minimal new impoundment facilities because public concern over environmental costs of altering stream flows can easily manifest itself in legal barriers to impoundment. For the same reason, minimum instream requirements may be regarded as real constraints. Even with minimum or no new impoundment facilities, between 350 and 450 thousand acre-feet of Yellowstone River water can be made available while meeting the NGPRP water work group's minimum instream requirement. While this falls far below the industrial water options applied for on the Yellowstone system, it does cover the requirements of coal processing plants at the level of development considered "most probable" by the NGPRP water work group (see Table 10).

Other potentially significant barriers to water use are Indian water rights and interstate compacts governing allocation of Yellowstone water. These legal problems add uncertainty to the assessment of long-term prospects for coal development in the Great Plains. But even if these uncertainties are ignored, the decision to use surface water for coal development must account for the very considerable costs of delivering water to processing sites.

Table 9 - Summaries of water available and estimates of water cost at specified locations in the Yellowstone River Basin.

Withdrawal point	Water available	Water cost at Sheridan area	Water cost at Gillette area	Water cost at Colstrip
	1,000 ac. ft.	----------------per acre-foot----------------		
Hardin, Montana	353[a] - 611[b]	\$144 to \$210	\$200 to \$300	\$47 to \$154
Armelles Creek	474[a] - (c)	\$160 to \$266	\$234 to \$328	\$47 to \$167
Miles City	484[a] - (c)	\$146 to \$183	\$162 to \$256	\$92 to \$172
Moorehead Reservoir (Powder River)	77 - 178[d]		\$90 to \$134	
New Tongue Reservoir	63 - 92[e]	\$48 to \$84		

(a) Using water from Boyson and Bighorn Rivers (existing)

(b) Custer Reservoir Built

(c) Considerable potential exists for storage on the Mainstem Yellowstone

(d) With lower Clear Creek Reservoir added

(e) With Rockwood Reservoir added

Source: Appendices of NGPRP, 1977

Table 10 Water requirements in Yellowstone River System for three levels of coal development.

Projected NGPRP Scenarios	Water required per year (1,000 acre-foot) Sheridan area	Gillette area	Colstrip
Base	58.5	23	--
Most probable	129	53	139.5
Extensive	219.0	173	379.5

Source: NGPRP Water Work Group Report

Table 11 Water requirements in North Dakota for three levels of coal development.

Projected Scenario	Water required per year (1,000 acre-foot) Knife River	Dickinson	Southwest
Base	23	--	--
Most probable	256	23	69
Extensive	526	53	99

Source: NGPRP Water Work Group Report

Reference to Table 10 and Figure 2 shows the transportation problem involved. One site for withdrawal of water from the Yellowstone system is at Hardin, Montana on the Bighorn River, from which an aqueduct would transport Boysen Lake and Bighorn Lake water southeast through the Sheridan area and possibly on to the Gillette area. Another aqueduct from Hardin could serve the Colstrip area. A second withdrawal site is at the mouth of Armelles Creek at a point on the Yellowstone River about 30 miles downstream from the mouth of the Bighorn River. An aqueduct from this point could serve the Colstrip area and could be enlarged to serve the Sheridan and Gillette areas. A third site is at Miles City near the confluence of the Yellowstone and Tongue Rivers. Two locations have been specified as possible withdrawal sites from Lake Sakakawea to serve processing plants in the North Dakota coal fields.

The last three tables give a thumbnail sketch of the costs and physical limitations of mine-mouth coal processing in the Northern Great Plains. Table 9 lists several combinations of aqueducts with water costs per acre-foot at Yellowstone Basin processing sites and water availability at with-drawal points. Table 10 shows the water requirements of the same three processing sites under three different development scenarios constructed by the NGPRP. Table 11 shows a similar display of requirements in the North Dakota area.

It can be concluded that water availability for coal development in the Northern Great Plains does not hinge on quantities of water in the region so much as the location of water and the cost of transporting it to mine sites. The analysis of these costs must take account of alternative schemes, such as moving coal to industrial areas via unit trains. In this regard there are a

number of uncertainties involved in predicting amounts of water needed. Most of these lead to the anticipation that the demand on surface water may be less and not more than expected. Demand would be less if there were breakthroughs in heat transfer technology (making cooling less water-intensive) or a discovery of economically exploitable deep aquifers. Uncertainties such as these should mean that a high discount rate will have to be applied to projected benefits from highly specialized and irreversible investment in aqueducts and dams.

CHAPTER V FOOTNOTES

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GLOSSARY

1. Temp C - Temperature in degrees Celsius
2. DO - Dissolved oxygen
3. BOD - Biochemical oxygen demand
4. pH - A measure of acidity
5. TDS - Total dissolved solids
6. SS - Suspended solids
7. T-NO_3 as N - Nitrogen in the form of nitrates
8. NH_3 - Ammonia
9. T-PO_4 as P - Phosphorous in the form of phosphates
10. Pb - Lead
11. Cu - Copper
12. Hg - Mercury
13. F - Fluoride
14. Se - Selenium
15. Al - Aluminum
16. B - Boron
17. Zn - Zinc
18. mg/l - milligrams per liter
19. cfs - cubic feet per second
20. ug/l - micrograms per liter